INCORPORATING EXTERNALITIES AND UNCERTAINTY INTO LIFE-CYCLE COST ANALYSES

THESIS

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Abstract

Executive Order 13514 requires federal agencies to consider economic and social benefits and costs when evaluating projects and activities based on life-cycle return on investment. The generation of energy used by federal facilities imposes social externalities, most notably air pollution, upon society. This research utilized the social costs of carbon dioxide, oxides of nitrogen, and sulfur dioxide to develop a probabilistic life-cycle full-cost analysis tool for the analysis of energy efficiency projects. This tool was then used to investigate the effects of incorporating social externalities and uncertainty into life-cycle cost analyses of energy efficiency projects. Calculation of the social benefits of air pollutant emissions reductions was found to have a statistically significant impact on the savings-to-investment ratio (SIR) of energy efficiency projects. A sensitivity analysis indicated that the SIR was most sensitive to the total initial investment of the project and the energy usage savings, but less sensitive to small changes in the values of the social benefits of air pollutants. The ranking of projects was found to be affected by the inclusion of social benefits in calculation of the SIR.

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I. Introduction

Sustainable development has become a major concern for societies around the world to guarantee that future generations are able to have the same opportunities enjoyed by the current generation. One way to encourage the sustainable use of natural resources is to account for the full cost of those resources when making investment decisions regarding our built infrastructure, which accounts for a large percentage of our energy and natural resource consumption. While this is a great challenge, it is also an opportunity to improve the sustainability of our built infrastructure. The application of full-cost accounting principles to facility investments may help encourage the consideration of sustainability when faced with multiple investment alternatives. This research seeks to provide a full-cost accounting tool for use in the evaluation of energy efficiency projects.

Background

In 1987, the World Commission on Environment and Development, led by Norwegian Prime Minister Gro Harlem Brundtland, published *Our Common Future*, commonly called the Brundtland Report (Kates, 2005). The report provides the most frequently quoted definition of sustainable development: development that "meets the needs of the present without compromising the ability of future generations to meet their own needs." This definition deals with the central tenet of sustainable development,

namely the idea of equitable opportunity amongst generations. The sustainability criterion, according to Tietenberg (2006), states that the minimum requirement for sustainability is that future generations should be left no worse off than current generations. This concept follows closely from the definition of sustainable development, but does little to describe specifically in what ways we must ensure future generations are as well off as the current generation. Some would argue that our current resource consumption is not disadvantaging future generations because we are leaving them with a more economically wealthy society, and they will likely have the technology to find substitutes for current natural resources. This idea of the substitutability of natural and physical (i.e., man-made) capital is central to the difference between two principles of sustainability, strong and weak sustainability.

Weak sustainability requires that the total capital stock (natural plus physical) does not decline over time, based on the premise that there is a high degree of substitutability between physical and natural capital. In essence, proponents of weak sustainability believe that technology will solve the problems of resource scarcity in the future. The concept of strong sustainability requires that the stock of natural capital not decline over time, based on the idea that there is a low degree of substitutability between physical and natural capital (Tietenberg, 2006). Our current growth and resource consumption meet neither of these principles of sustainability as we consume non-renewable resources and continue to pollute at a rate higher than the planet's assimilative capacity. The question then arises, how do we ensure that our growth is sustainable now and into the future?

Tietenberg (2006) proposes a number of principles to encourage sustainability, although none guarantee the strong sustainability required to truly ensure that future generations are left off as well as we are. One principle he proposes, the Full Cost Principle, states that those who use a natural resource should pay its full cost. This principle is based on the idea that humanity has a right to a safe and healthy environment and that this right has been surrendered involuntarily due to a lack of oversight of the consumption of natural resources. The Full Cost Principle requires that one who uses a natural resource pays not only the costs to supply that resource, but also the opportunity costs and the environmental externalities associated with the extraction of that resource. Externalities occur when the damage caused by a decision is borne by people other than the agent making that decision. For example, the use of electricity creates negative externalities such as air pollution, which are borne by society as a whole. In order to adhere to the Full Cost Principle, inappropriate subsidies on natural resources, which serve to artificially reduce the price of resources, would have to be removed (Tietenberg, 2006). According to neoclassical economics, artificially low prices lead to overconsumption of a resource. Social welfare is maximized when the full cost equals the value in use of that resource (Rogers, 1998). Therefore, the consideration of the full cost of a resource will encourage its conservation and efficient use.

Society at large often bears the costs of the environmental externalities caused by resource consumption. These costs are borne through environmental degradation, which may have economic impacts such as reduced crop yields, rising sea levels due to climate change, or reduced tourism to an area affected by pollution. The government at every level frequently bears these costs in one way or another, whether it is the costs of

cleaning up pollution or reduced tax revenue due to decreased economic activity. By factoring these environmental externalities into current decision-making, the government can consider future costs that will likely be borne in the future. One program intended to reduce energy use in the Department of Defense, the Energy Conservation Investment Program (ECIP), considers the direct financial benefits of reduced energy consumption, but does not account for the environmental benefits of reduced energy consumption.

The ECIP program is a subset of the Defense Agencies Military Construction (MILCON) program specifically designated for energy reduction projects. Energy reduction projects from each military service are compiled and approved by Congress for funding (ECIP Guidance, 1993). Life-cycle cost analyses of each project are required to be completed in order to determine the financial benefits accruing as a result of reduced energy demand. Additionally, several supplemental financial measures including the payback period and the savings-to-investment ratio (SIR) are calculated and used to prioritize projects. All ECIP projects should have a payback period of less than 10 years and an SIR of 1.25 or greater (ECIP Guidance, 1993). The program guidance also requires the use of a sensitivity analysis to determine whether expected changes might alter the economic benefits of the project. The increased risk identified as the result of a sensitivity analysis may be used to lower a project's programming priority (ECIP Guidance, 1993).

Research Problem

Life-cycle cost analyses of Energy Conservation Investment Program (ECIP) projects consider the financial benefits of reduced energy consumption, but do not consider the societal benefits of energy usage reductions when making financial investment calculations. While these societal benefits do not directly accrue to the entity using or producing the electricity, they are realized by society as a whole in the form of reduced economic impacts of air pollution. Executive Order 13514 requires that each agency "take into consideration environmental measures as well as economic and social benefits and costs in evaluating projects and activities based on life-cycle return on investment." One way in which environmental, economic, and social costs can be considered in decision-making is to factor them directly into economic analyses when making energy-efficiency project decisions. The National Institute of Standards and Technology (NIST) Building Life-Cycle Cost (BLCC) tool, the primary life-cycle cost analysis tool used for ECIP projects, fails to account for the societal benefits of air pollutant emissions reductions. Additionally, it fails to account for the uncertainty inherent in the estimates of project costs and energy consumption. Both the societal benefits of pollutant reductions and the uncertainty in input parameters can have a large influence on the cost-effectiveness of an energy efficiency project. Therefore, the consideration of this information provides the decision-maker valuable insight into the potential return on investment for a single project as well as a portfolio of potential projects.

Research Objective

The main objective of this research was to develop a probabilistic life-cycle full-cost analysis tool that incorporates social externalities into Energy Conservation Investment Program (ECIP) project investment decisions and provides decision-makers with a means to characterize the uncertainty inherent in these decisions. A secondary objective of this research was to utilize the probabilistic life-cycle full-cost analysis tool to investigate the impact of incorporating social externalities into life-cycle cost analyses of investment decisions. This research focused on the following investigative questions:

1. Which environmental externalities should be considered in the model and what values should be used to quantify and monetize these externalities?
2. Does the incorporation of environmental externalities have a statistically significant impact on life-cycle cost analyses of energy efficiency projects?
3. How sensitive is the savings-to-investment ratio to variations in input parameters?
4. What additional insight is gained through the use of Monte Carlo simulation of life-cycle costs and benefits over a standard deterministic approach?
5. How does the incorporation of environmental externalities and Monte Carlo simulation affect the ranking of Energy Conservation Investment Program (ECIP) projects?

Methodology

A probabilistic life-cycle full-cost analysis tool was developed to incorporate the social benefits of air pollutant emissions reductions in life-cycle cost analyses of Energy Conservation Investment Program (ECIP) projects. The social costs of air pollutants were

used to quantify the benefits of reduced air emissions associated with energy use reductions. The tool was developed to be used in conjunction with the NIST Building Life-Cycle Cost (BLCC) program, which performs a deterministic life-cycle cost analysis of ECIP projects. The outputs from the BLCC program are used as inputs for the probabilistic life-cycle full-cost analysis tool. The financial benefits of the energy use reductions are then quantified and a Monte Carlo simulation is performed. The tool then provides expected values and probability distributions of the supplemental financial measures simple payback (SPB), savings-to-investment ratio (SIR), Btu-to-investment ratio (BIR), CO_2-to-investment ratio (CIR), and adjusted internal rate of return (AIRR). The tool also provides a sensitivity analysis of the supplemental financial measures based on fixed percentage deviations of input parameters. The probabilistic life-cycle full-cost analysis tool was then used to analyze several projects from the fiscal year 2012 (FY12) ECIP program. The analysis included investigation of the statistical significance of the inclusion of the social benefits of air pollutant emissions reductions on the supplemental financial measure of SIR. Additionally, sensitivity analyses were completed on several of the projects by varying the expected values of several input parameters. Deterministic values of the supplemental financial measures were then compared with the probability distributions of the same measures. Finally, the ranking of the top ten projects from the FY12 ECIP program was analyzed for the effect of the inclusion of the social benefit of air pollutant emissions reductions and the use of Monte Carlo simulation.

Assumptions/Limitations

The probabilistic life-cycle full-cost analysis model constructed in this research accounts for only the operational life environmental impacts of the projects under consideration, not the environmental externalities of the entire life-cycle of the materials used in the project. There are a large number of environmental costs associated with the extraction of resources and the manufacture of construction materials; however, these were not factored into the analysis. The model relies on estimates of future project costs and energy consumption, which are highly uncertain. Additionally, the societal costs of air pollutant emissions due to energy generation are highly uncertain and are themselves based on models with a large number of assumptions, highly uncertain inputs, and value judgments that can affect the values by orders of magnitude. The use of Monte Carlo simulation and the inclusion of a sensitivity analysis within the tool allows the decision-maker to at least be aware of the large uncertainty in the model and potentially adjust their decision-making accordingly.

Review of Chapters

Chapter 2 provides a review of literature, including the concepts of life-cycle costing, discounting, environmental externalities, social costs of air pollutants, and the use of simulation to handle uncertainty. Chapter 3 outlines the methodology used to construct the probabilistic life-cycle full-cost analysis tool and perform analysis on ECIP projects. Chapter 4 outlines the results of the analysis of ECIP projects using the tool and compares a traditional life-cycle cost analysis with a probabilistic life-cycle full-cost analysis. Chapter 5 provides a discussion of the results presented in Chapter 4 and concludes with the applicability of this research and opportunities for future research.

II. Literature Review

This chapter will provide an overview of literature relevant to the study of sustainability and economic analysis. First, the concept of sustainable development will be defined and discussed. Next, the use of discounting will be discussed, both in terms of its implications regarding intergenerational equity and in terms of its use to account for the time-value of money in economic analyses. The concepts of life-cycle costing will then be introduced. This will be followed by a discussion of externalities and the ways in which the environment is valued to monetize these externalities. Next, the calculation of the societal costs of carbon dioxide and other air pollutants will be discussed, followed by a discussion of the full cost of water consumption. Finally, a discussion of Monte Carlo simulation will conclude the chapter.

Sustainable Development

There are a variety of definitions of sustainable development; however, the definition provided in *Our Common Future* is the most frequently cited one (Kates, 2005). The report defines sustainable development as development that “meets the needs of the present without compromising the ability of future generations to meet their own needs.” Sustainable development seeks to balance economic growth with social and environmental concerns. Proponents of sustainable development recognize that development must occur to improve the lives of the world’s poor, but the environment must be spared to continue to provide critical services and resources for future generations (Kates, 2005). Sustainable development implies limits to growth, imposed by

the ability of the planet to absorb the effects of human activities. Additionally, the planet must be able to provide services to sustain human life. The services provided, including clean air and clean water, are vital to the survival of humans on this planet. In fact, Costanza et al. (1987) estimated the total value of the world's ecosystem services at $33 trillion/year, compared to global GNP of $18 trillion/year. Sustainable development also implies increased social equity, sharing the fruits of economic growth with all members of society.

Costanza and Daly (1992) differentiate between development and growth. They define growth as "throughput-increasing technical progress" and development as "efficiency-increasing technical progress." They further state that "growth is destructive of natural capital and beyond some point will cost us more than it is worth – that is, sacrificed natural capital will be worth more than the extra man-made capital whose production necessitated the sacrifice." Additionally, they state "Development, that is qualitative improvement, does not occur at the expense of natural capital. There are clear economic limits to growth, but not to development." Growth cannot be sustained indefinitely on a finite planet due to limited resources; development is required to improve mankind's quality of life while bringing our resource consumption within sustainable levels (Costanza & Daly, 1992). There is some disagreement as to what level of resource consumption or natural capital destruction is truly sustainable in the long term.

Capital, as defined by Costanza and Daly (1992), is "a stock that yields a flow of valuable goods or services into the future." They distinguish between stocks and flows, stating that a sustainable flow is "natural income" while the stock that yields that

sustainable flow is “natural capital.” They further define two main types of natural capital, renewable and nonrenewable natural capital. In addition to natural capital, total capital is made up of man-made capital, of which there are two types – manufactured capital and human capital. Manufactured capital consists of buildings, tools, etc. Human capital consists of skills, knowledge, and culture. According to Costanza and Daly (1992), only manufactured capital was considered capital in the past because natural capital was so abundant in relation to the human scale of consumption; however, due to increasing population and consumption patterns, this is no longer the case. Mankind is entering an era in which natural capital will be the limiting factor to consumption. The importance of maintaining the various types of capital leads to two primary concepts of sustainability – weak sustainability and strong sustainability.

The sustainability criterion states that resource use by the current generation should not exceed a level that will prevent future generations from achieving the same quality of life. The concept of weak sustainability meets the sustainability criterion by ensuring that the value of the total (natural plus man-made) stock of capital does not decline over time. This assumes that increased man-made capital (made up of manufactured and human capital) can substitute for natural capital as it declines (Tietenberg, 2006). Harte (1995), while not explicitly supporting the concept of weak sustainability, states “It is possible to exploit non-renewable resources in a quasi-sustainable manner by limiting their rate of depletion to the rate of development of renewable substitutes.” Therefore, this would allow a non-renewable resource like oil to be consumed at a rate equal to the development of alternative forms of energy. Costanza and Daly (1992) do not agree with the concept of weak sustainability and state that “This

assumption of near-perfect substitutability (high constant elasticity of substitution) has little support in logic or fact." They support their argument by stating that "Manufactured capital is itself made of natural resources, with the help of human capital (which also consumes natural resources)." Further, "A physical analysis of 'production' reveals that it is really a transformation process – a flow of natural resource inputs is transformed into a flow of product outputs by two agents of transformation, the stock of laborers (human capital) and the stock of manufactured capital at their disposal." They conclude, "The relationship is overwhelmingly one of complementarity, not substitutability." John Hartwick (1977) suggested a means by which to meet the weak sustainability criterion.

Hartwick (1977) suggested a rule, that has since come to be known as the Hartwick rule, which meets the requirements of weak sustainability. He suggested that an amount equal to the reduction in value of a resource stock as it is consumed should be invested in physical capital, thus guaranteeing that the total stock of capital does not decline over time. This rule assumes that investing a specific amount in physical capital produces physical capital of equal value to the natural capital that was consumed. Neither the Hartwick rule nor the concept of weak sustainability truly meets the sustainability criterion, especially with current technology. Many of the natural processes that humankind relies on, such as photosynthesis and the hydrologic cycle, could not affordably be reproduced using technology in the foreseeable future. Therefore, a more robust principle to implement sustainability is required.

Costanza and Daly (1992) believe that the alternative definition of sustainability, strong sustainability, is the true minimum requirement for sustainability. Strong sustainability requires that the total stock of each type of capital individually does not

decline over time. This assumes a low degree of substitutability between the types of capital. According to Harte (1995), "We should accept that it is often impractical and perhaps undesirable to hold natural capital intact in its entirety, but it is also counter to the idea of sustainability to bequeath a stock of natural capital to future generations that is incapable of yielding sufficient resource flows (i.e., 'income') to fulfill their potential needs and aspirations." His view thus allows some level of natural resource consumption to meet the definition of sustainability. The difficulty is then determining what level of resource consumption is sustainable, or at least how mankind can approach a sustainable level of resource consumption based on the needs of future generations.

Sustainability requires that the needs of future generations be considered by the current generation when making decisions. In order to compare generational needs across time, these needs must be quantified and translated to a common time period based on the time value of money. The mechanism for adjusting economic values across time is called discounting, and it is the subject of the next section.

Discounting

The concept of discounting is used to account for the time value of money in economic analyses. The time value of money is exemplified by the fact that a dollar today is worth more to someone than a dollar in the future. The additional amount of money that would be required in one year, expressed as a percentage, to prompt a decision-maker to forgo the dollar of consumption today represents that decision-maker's discount rate. The discount rate takes into account the social opportunity cost of capital (Tietenberg, 2006). The discount rate used by a decision-maker greatly affects the

relative importance of costs today and costs far in the future. A discount rate of 0% essentially means that a dollar today is equal in value to a dollar in the future. A high discount rate essentially minimizes the importance of costs in the future relative to costs today. Economic analyses use the concept of discounting to investigate the cost effectiveness of investment decisions by discounting all future costs and benefits back to a common time period and comparing alternatives based on different financial measures. In addition to its usefulness in economic analyses, discounting plays an important role in environmental economics.

The discount rate is an important measure of intergenerational equity in that it measures the relative importance of the interests of the current generation and the interests of future generations, a key component of sustainability. The discount rate is a major determinant of the allocation of resources amongst generations (Tietenberg, 2006). According to Costanza and Daly (1992),

> … discounting at best only reflects the subjective valuation of the future to presently existing individual members of human society. Discounting is simply a numerical way to operationalize the value judgment that (1) the near future is worth more than the distant future to the present generation of humans, and (2) beyond some point the worth of the future to the present generation of humans is negligible.

Some argue that for environmental decisions, specifically those that deal with intergenerational equity, the discount rate should be as low as possible. Costanza and Daly (1992) state that

> …the discount rate used by the government for public policy decisions (like valuing natural capital) should be significantly lower than the rate used by individuals for private investment decisions. The government should have greater interest in the future than individuals currently in the market because continued social existence, stability, and harmony are public goods for which the

government is responsible, and for which current individuals may not be willing to fully pay.

In fact, a small minority of scholars even argue a negative discount rate, which serves to value future resources more highly than present resources (Costanza & Daly, 1992). A number of different methods have been proposed to determine the appropriate discount rate to use in various applications.

Arrow et al. (1996) outlined two approaches to determining discount rates and called these the “descriptive” and “prescriptive” approaches. The descriptive approach takes a non-normative perspective based on observation of the actual choices people make. Those who advocate for the descriptive approach call for inferring discount rates from market rates of return because this represents the actual rate people use when making decisions. The prescriptive approach specifies a social welfare function that allows the decision-maker to incorporate normative judgments, such as ideas of intergenerational equity. The Ramsey Equation (Ramsey, 1928) provides a useful framework for determining the discount rate based on both descriptive and prescriptive concerns. The Ramsey Equation is defined as:

$$r = \rho + \eta g$$

where r is the Ramsey discount rate, ρ is the pure rate of time preference, η is the coefficient of relative risk aversion or elasticity of marginal utility of consumption, and g is the growth rate of per capita consumption.

The pure rate of time preference is defined by the rate of substitution between present and future consumption under the assumption that present and future consumption are equal (i.e., $g = 0$). The second term in the equation, ηg, reflects the

growth rate of material happiness measured in terms of underlying personal utility. Therefore, incorporation of these terms allows the decision-maker to apply both prescriptive and descriptive judgments when selecting an appropriate discount rate; however, the judgments of decision-makers when selecting discount rates may present a problem of bias in the results.

One major issue with discounting is that it allows a decision-maker to bias their results by selecting a specific discount rate. Almost any investment can be shown to be cost effective or not, depending on which discount rate is used for analysis. In an attempt to limit federal agency decision-makers' ability to use their own discount rates to encourage or discourage specific energy or water conservation projects, the National Institute of Standards and Technology (NIST) provides discount rates annually in the annual supplement to NIST Handbook 135. According to the 2010 annual supplement to Handbook 135, the real discount rate (excluding general price inflation) for 2010 is 3.0%. The nominal rate (including general price inflation) is 4.0%. The implied long-term average rate of inflation is 0.9%. The real discount rate is based on the long-term Treasury bond yield for the 12 months preceding the release of the report. NIST also publishes the rate of inflation for use in federal economic analyses because this affects the nominal discount rate that should be used.

Inflation accounts for the decrease in the purchasing power of money over time. Economic analyses can handle inflation in two ways, either the analysis can be done in current dollars or constant dollars. Analyses accomplished in constant dollars provide the cost in dollars of uniform purchasing power, so the real discount rate should be used for analysis. Analyses completed in current dollars provide costs in the dollars of the year in

which the cost takes place. Therefore, these costs must be discounted using the nominal discount rate, which factors in the rate of inflation. Additionally, the time in the year when the costs take place is a concern.

NIST Handbook 135 uses the end-of-year discounting convention, which assumes that all costs within a given year occur at the end of that year. The Department of Defense uses mid-period discounting for Energy Conservation Investment Program (ECIP) projects. The NIST BLCC program calculates life-cycle costs according to the NIST Handbook 135 standard and utilizes the correct discount rate and a discounting convention depending on which option is selected within the tool. This allows a measure of consistency in the selection of discount rates and the calculation of life-cycle costs. The next section outlines the use of discounting to perform life-cycle cost analyses of facility projects.

Life-Cycle Costing

The NIST Handbook 135 is a guide to the life-cycle costing (LCC) methodology established by the Federal Energy Management Program (FEMP) under the U.S. Department of Energy. This methodology is suitable for economic analyses of energy and water conservation projects. It conforms to the requirements for life-cycle costing set forth in 10 CFR 436, Subpart A. Handbook 135 defines the life-cycle cost (LCC) of a project as “the total cost of owning, operating, maintaining, and (eventually) disposing of the building system(s) over a given study period (usually related to the life of the project), with all costs adjusted (discounted) to reflect the time value of money." Each year, the annual supplement to Handbook 135 is published, which includes the current discount

rate and energy price indices. The energy price indices are calculated from energy price forecasts provided by the Department of Energy's Energy Information Administration (EIA). The 2010 Annual Supplement additionally began providing potential future carbon prices based on a variety of carbon policy scenarios, including that put forth in the American Clean Energy and Security Act (ACESA) of 2009 (H.R. 2454), which ultimately did not pass the U.S. Senate and never became law.

The assessment of investment decisions regarding sustainability based on life-cycle cost is required by a number of executive orders, including Executive Order 13423 and Executive Order 13514. Executive Order 13423 *Strengthening Federal Environmental, Energy, and Transportation Management*, issued by President George W. Bush in 2007, states that beginning in FY 2008, federal agencies should "reduce water consumption intensity, relative to the baseline of the agency's water consumption in fiscal year 2007, through life-cycle cost-effective measures by 2 percent annually through the end of fiscal year 2015 or 16 percent by the end of fiscal year 2015." It further defines life-cycle cost-effective to mean "the life-cycle costs of a product, project, or measure are estimated to be equal to or less than the base case (i.e., current or standard practice or product)." Executive Order 13514 *Federal Leadership in Environmental, Energy, and Economic Performance*, issued by President Barack Obama in 2009, states that each federal agency "shall develop, implement, and annually update an integrated Strategic Sustainability Performance Plan that will prioritize agency actions based on life-cycle return on investment." Additionally, each agency shall "take into consideration environmental measures as well as economic and social benefits and costs in evaluating projects and activities based on life-cycle return on investment." The order later states

> It is further the policy of the United States that to achieve these goals and support their respective missions, agencies shall prioritize actions based on a full accounting of both economic and social benefits and costs and shall drive continuous improvement by annually evaluating performance, extending or expanding projects that have net benefits, and reassessing or discontinuing under-performing projects.

The U.S. Department of Transportation (DOT) Office of Asset Management published the *Life-Cycle Cost Analysis Primer* in 2002 to encourage the use of life-cycle cost analysis (LCCA) to evaluate alternative infrastructure investment options. LCCA allows decision-makers to compare projects that provide the same level of service on a life-cycle cost basis (LCCA Primer, 2002). LCCA involves factoring all of the costs associated with an investment alternative and discounting them back to present dollars. LCCA is a subset of benefit-cost analysis (BCA), which is defined in this report as "an economic analysis tool that compares benefits as well as costs in selecting optimal projects or implementation alternatives." LCCA, unlike BCA, considers only the costs associated with an investment decision and not its benefits. Therefore, LCCA is only appropriate to compare alternatives that provide the same benefits, while BCA can be used to determine whether a project should be undertaken at all (if its life-cycle benefits exceed its life-cycle costs) (LCCA Primer, 2002).

In 2001, the Federal Facilities Council Ad Hoc Task Group on Integrating Sustainable Design, Life-Cycle Costing, and Value Engineering into Federal Acquisition released their report, titled *Sustainable Federal Facilities: A Guide to Integrating Value Engineering, Life-Cycle Costing, and Sustainable Development*. The primary objective of the report was to "develop a framework to show how federal agencies can use value engineering and life-cycle costing to support sustainable development for federal

facilities and meet the objectives of Executive Order 13123" (Sustainable Federal Facilities, 2001). The report notes the conflict between federal acquisition policies, which require the use of life-cycle costing, and the federal budget process, which emphasizes reduction in the first cost of facilities. While they believe life-cycle costing is important to promote sustainability of federal facilities, they acknowledge that federal acquisition processes do not encourage the consideration of life-cycle costs when making investment decisions. Tools such as value engineering, defined in the report as "a strategic thinking process that involves the systematic and objective assessment of project component alternatives," are often applied later in the design process in order to reduce first costs. The authors argue that this is an incorrect use of value engineering because it can often remove integrated sustainable design features, which increases life-cycle costs while decreasing first costs.

The report defines life-cycle costing as:

> A methodology used for facility acquisitions that employs a comprehensive economic analysis of competing alternatives. The analysis compares initial investment options and identifies least-cost alternatives for a project or acquisition over its serviceable or useful life span. Life-cycle costing examines the associated ownership costs of competing alternatives by discounting both the positive and negative cash flows throughout the facility's service life (Sustainable Federal Facilities, 2001).

The authors state that life-cycle costing and value engineering should be used in the conceptual design phase to identify and select alternatives that have the lowest life-cycle costs. The report goes on to describe the various phases of federal facility acquisition and how sustainable principles can best be incorporated in each phase.

Gluch and Baumann (2004) examined the effectiveness of the life-cycle costing approach to environmental decision-making and concluded that there are a number of

issues with its use. Specifically, their criticisms cite four inherent limitations of applying neoclassical economic theory, upon which life-cycle costing is based, to environmental decision-making. First, they argue that neoclassical economic theory cannot handle uncertainty because it assumes the decision-maker is always rational and has access to all the information required for an informed decision. Second, they argue that neoclassical economics assumes that alternatives are always available, which is rarely the case with environmental decisions that are often irreversible. For example, the extinction of a species, the authors argue, is not considered an issue under neoclassical economic theory because the species can be replaced without affecting the ecosystem. Thirdly, neoclassical economic theory ignores items that have no owner and items for which there is no market, which includes most environmental services. Finally, neoclassical economic theory oversimplifies complex environmental problems and attempts to boil them down into a monetary figure. This ignores the inherent complexities and interrelationships within the natural world, and ignores or downplays the intrinsic value of nature. However, the authors concede that translating environmental factors into monetary terms does allow them to be considered when making investment decisions. Gluch and Baumann (2004) conclude that LCC-oriented tools may be useful in practice if the decision-maker is aware of their limitations. They state that the primary benefit of performing an LCCA may not be the results of the analysis, but the involvement required to carry out the LCCA.

Life-cycle costing provides a means to compare current and future costs in an economic analysis. The direct costs resulting from decisions regarding natural resource use are generally fairly easy to determine. The user of a resource pays the resource

provider a known amount of money for the ability to consume that resource. A problem arises when the price paid by the consumer is less than the full cost of the resource. A significant portion of the difference between the market price and the full cost is made up of the externalities associated with the consumption of the resource, which imposes costs on agents not involved in making the decision to consume the resource.

Environmental Externalities

Externalities occur when the agent making a decision does not bear all of the costs of that decision (Tietenberg, 2006). Externalities in markets lead to a number of problems. Because the externality is not factored into the cost of the resource, the price is artificially low and therefore demand is artificially high. This fact has a number of implications for the allocation of commodities causing pollution externalities. These implications include the output of the commodity being too large, the production of too much pollution, a lack of incentive to search for ways to yield less pollution per unit of output, and discouragement of reuse or recycling of the polluting substance (Tietenberg, 2006). Koomey & Krause (1997) state that pollution represents an external cost “because damages associated with it are borne by society as a whole and are not reflected in market transactions.” Additionally, they define externalities in terms of insults and pathways. Insults are “humankind’s physical and chemical intrusions into the natural world.” Pathways are the ways in which insults are converted to stresses. These stresses lead directly to societal costs, or externalities. Koomey & Krause (1997) argue for the importance of incorporating a value of externalities into economic analyses in order to ensure that these costs are captured by the decision-makers causing the externality. While

many of the direct costs in an economic analysis can easily be determined, the costs of environmental externalities are less straightforward to determine. As a result, a number of researchers have suggested methods by which a reasonable value can be placed on the environment. These methods allow a determination of the decrease in value of natural stocks due to consumption of natural resources, and therefore the societal costs of that consumption.

Environmental Valuation

Many scholars have argued against the use of neoclassical economic theory for valuation of the environment. However, Tietenberg (2006), among others, has argued that while valuing the environment is controversial, not doing so leaves the environment out of the equation when completing economic analyses. In order to ensure that the environment is considered adequately in an economic analysis, it is required to place a value on it. It may be necessary to value both stocks (e.g., a stock of trees) and flows (e.g., the harvest of timber from the forest). The value of a stock should be equal to the present value of the future stream of services flowing from the stock. Both stocks and flows have three main components of value. These are use value, option value, and nonuse value (Tietenberg, 2006; Markandya, 2002). Use value represents the value of direct use of a natural resource (for example, timber harvested from a forest). Option value reflects the value placed on the future ability to use the environment. Nonuse value reflects the value people place on improving or preserving resources that will never be used. The total willingness to pay is defined as the sum of these three components of value (Tietenberg, 2006). By definition, the concept of value is anthropocentric because it

reflects the contribution something makes to human welfare, where human welfare is measured in terms of each individual's assessment of their own well-being. Additionally, value is somewhat specific to each individual as an individual's willingness to pay or willingness to accept compensation is a result of their own endowment of wealth (Bockstael, 2000). A number of methods are utilized for determining the value of environmental resources.

Freeman (1993) outlines a number of these valuation methods, differentiating the methods based on two characteristics of the methods. The first characteristic deals with whether the data are derived from observations of people acting in real-world scenarios or whether data are derived from peoples' responses to hypothetical questions of the form "what would you do if…?". The second characteristic deals with whether the method yields monetary values directly or whether monetary values must be inferred. This leads to four different types of valuation methods: direct observed, indirect observed, indirect hypothetical, and direct hypothetical methods. Direct observed methods involve the use of competitive market prices or results from simulated markets set up to learn about individual values. The observations are based on actual choices made by people acting to maximize their own utility. Indirect observed methods are also based on actual people maximizing their own utility, but doing so in a referendum setting. An example is the travel-cost method, which measures the value of a recreational resource by evaluating the amount of money spent by people to access that resource (Tietenberg, 2006). Indirect hypothetical methods derive data from peoples' response to hypothetical questions, rather than their actual behavior. Direct hypothetical methods create hypothetical markets and derive data by asking people about the values they place on environmental services.

The methods of environmental valuation, along with a number of other economic principles, have been applied to arguably one of the most pressing environmental issues facing mankind – global climate change. The best method yet devised to deal with climate change is to decrease emissions of greenhouse gases (GHGs). In an effort to affect public policy decisions, a number of researchers have applied various economic concepts to determine a marginal damage cost (or alternatively, social cost) of a ton of carbon dioxide emitted into the atmosphere.

Societal Costs of Carbon Dioxide

There is little disagreement amongst scientists that the global average surface temperature is increasing, and that the majority of the observed warming is due to human release of greenhouse gases (GHGs). According to the Synthesis Report of the Fourth Assessment Report from the United Nations Intergovernmental Panel on Climate Change (IPCC), "Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level" (IPCC, 2007). Further, "Most of the observed increase in global average temperatures since the mid-20th century is very likely [greater than 90% certainty] due to the observed increase in anthropogenic GHG concentrations" (IPCC, 2007). Climate change poses a major sustainability concern, as it affects the potential ability of future generations to provide for themselves. Therefore, a major externality from mankind's use of energy is the emission of greenhouse gases, including carbon dioxide, methane, and nitrous oxide. These

externalities are rarely factored into the price of energy, leading to artificially low energy prices and therefore overconsumption of energy resources.

A number of studies have been completed that estimate the global damage costs of carbon dioxide; however, Tol (2005) argues that the marginal damage costs of carbon dioxide is more important to determine the impacts of carbon-reduction decisions. “Expressing total impacts in monetary terms is not sufficient to allow for a consistent comparison of the (avoided) impacts of climate change to mitigation costs…one needs to gain an understanding of the impact of climate change at the margin, i.e., the effect that can be achieved by a small alteration in greenhouse gas emissions” (Tol, 2005). After analyzing 103 estimates of the marginal damage costs of carbon dioxide collected from 28 studies, he found a fairly wide range of estimates for the marginal damage costs and that peer-reviewed studies tended to have lower estimates and less uncertainty in their results. He found a mean of $93 per ton of Carbon (tC) for all studies without any adjustment for quality and a mean of $43/tC among the peer-reviewed studies. Based on this research, it is apparent that there is some disagreement about how best to estimate the marginal damage costs of carbon dioxide, resulting in a great deal of uncertainty in any estimates of these costs.

Despite this uncertainty, Tol (2005) argues that “estimates of the marginal damage costs of carbon dioxide emissions, however controversial and uncertain, are useful if only to provide a benchmark for the costs of emission reduction policies.” He further argues that the estimates may actually be lower than the “true” value “because they tend to ignore extreme weather events; exclude low probability/high consequence scenarios, such as a shutdown of the thermohaline circulation or a collapse of the West-

Antarctic ice sheet; underestimate the compounding effect of multiple stresses; and ignore the costs of transition and learning." He also acknowledges the possibility that the estimates could be high, stating "however, studies may also have overlooked positive impacts of climate change and not adequately accounted for how development can reduce impacts of climate change." Overall, his study provides an important overview of the published research attempting to quantify the marginal damage costs of carbon dioxide.

In addition to Tol's 2005 study of the numerous estimates for the marginal damage cost of carbon dioxide, the IPCC performed a similar analysis for the Fourth Assessment Report with somewhat different results. According to the Synthesis Report,

> Peer-reviewed estimates of the social cost of carbon (net economic costs of damages from climate change aggregated across the globe and discounted to the present) for 2005 have an average value of US$12 per tonne of CO2, but the range from 100 estimates is large (-$3 to $95/tCO2). The range of published evidence indicates that the net damage costs of climate change are projected to be significant and to increase over time.

Therefore, the IPCC found a much lower mean estimate of the marginal damage costs of carbon dioxide than Tol's (2005) analysis of peer-reviewed studies completed in the same year. The Synthesis Report does state that this estimate is likely low because many non-quantifiable impacts are not accounted for. Another more recent study by the U.S. Government Interagency Working Group on Social Cost of Carbon utilized several integrated assessment models to estimate the value of the social cost of carbon for different discount rates.

In February 2010, the Interagency Working Group on Social Cost of Carbon, a working group made up of representatives from several U.S. federal government agencies and departments, released a report titled *Technical Support Document: Social Cost of*

Carbon for Regulatory Impact Analysis Under Executive Order 12866. The purpose of the report was to provide estimates of the social cost of carbon (SCC) to "allow agencies to incorporate social benefits of reducing carbon dioxide (CO_2) emissions into cost-benefit analyses of regulatory actions that have small, or 'marginal', impacts on cumulative global emissions" (Interagency Working Group on the Social Cost of Carbon, 2010). The working group defines the social cost of carbon as "an estimate of the monetized damages associated with an incremental increase in carbon emissions in a given year. It is intended to include (but is not limited to) changes in net agricultural productivity, human health, property damages from increased flood risk, and the value of ecosystem services due to climate change."

The report provides four estimates of the social cost of carbon (in dollars per metric ton of carbon dioxide) starting in year 2010 and every five years until 2050 under various discount rates. These results can be found in Table 1. The first three columns of SCC values in Table 1 are based on mean values from three different Integrated Assessment models at discount rates of 2.5%, 3%, and 5%. The fourth column represents the mean of the 95th percentile SCC estimates from the three models at a 3% discount rate. The 95th percentile values represent potential larger than expected impacts from temperature change.

The three integrated assessment models used in this report, the FUND, DICE, and PAGE models, are frequently cited in peer-reviewed literature and were used by the IPCC for their assessment report. These models combine climate processes, economic growth, and feedback between climate and the economy, allowing translation of carbon dioxide emissions into economic damages. Each model takes a different approach to

translating emissions into monetary damages, resulting in fairly different estimates of economic damages. The major model inputs that have the greatest impact on the estimated SCC are climate sensitivity, economic and population growth scenario, and discount rate.

The climate sensitivity, defined as the "long-term increase in the annual global-average surface temperature from a doubling of atmospheric CO_2 concentration relative to pre-industrial levels (or stabilization at a concentration of approximately 550 parts per million (ppm))," was modeled in this research by a probability distribution outlined by Roe and Baker (2007). The distribution was bounded between temperature increases of 0 and 10 °C with a median of 3 °C and a cumulative probability of two-thirds between 2 and 4.5 °C. Five different economic, population, and carbon emissions scenarios were used based on the Stanford Energy Modeling Forum exercise, EMF-22. The damages associated with emissions of a single metric ton of carbon dioxide were calculated into the future and were discounted back to present value. A Monte Carlo simulation was used in each model for each scenario and discount rate, resulting in 45 probability distributions of the SCC. The averages of the resulting 15 probability distributions associated with each discount rate were averaged to arrive at a single estimate for the SCC in each year based on each discount rate. The SCC increases each year due to the reduced ability of the climate system to cope with additional emissions. While this research does account for some of the uncertainties associated with economic damages of climate change, the authors note the inherent limitations of their approach and caution against the blind use of these values. They state that it is appropriate to consider the full range of values of the SCC in a regulatory analysis. While the social cost of carbon attempts to quantify the

environmental and social externalities of greenhouse gas emissions, these costs are not direct costs borne by the polluter or the consumer of energy. Several initiatives have been proposed to internalize these externalities in decision-making. Carbon taxation or cap and trade schemes attempt to put a price on emissions of greenhouse gases in an attempt to incentivize carbon emissions reductions. The magnitude of the carbon tax is therefore based on a consideration of the effect on consumption and not necessarily the social cost of the pollutants.

Table 1. Social Costs of CO_2, 2010-2050, ($/ton - in 2007 dollars) (Interagency Working Group on Social Cost of Carbon, 2010)

Discount Rate Year	5% Avg	3% Avg	2.5% Avg	3% 95th
2010	4.7	21.4	35.1	64.9
2015	5.7	23.8	38.4	72.8
2020	6.8	26.3	41.7	80.7
2025	8.2	29.6	45.9	90.4
2030	9.7	32.8	50.0	100.0
2035	11.2	36.0	54.2	109.7
2040	12.7	39.2	58.4	119.3
2045	14.2	42.1	61.7	127.8
2050	15.7	44.9	65.0	136.2

Due in part to the threat of global climatic change, the United States Congress has pursued legislation to put a price on greenhouse gas emissions. The American Clean Energy and Security Act (ACESA) of 2009 (House Resolution 2454) passed the United States House of Representatives in 2009 but failed to pass the United States Senate. This bill would have created a cap and trade program for greenhouse gases. As a result of the

potential pricing of greenhouse gases, the 2010 Annual Supplement to NIST Handbook 135 introduced a set of tables projecting potential future carbon prices. Three potential carbon policy scenarios were selected from an EPA analysis of ACESA 2009, leading to three potential levels of carbon pricing in the tables. The default scenario assumes all countries, including developing countries, begin to restrict carbon emissions over the next 40 years. The low scenario assumes that developing countries do not restrict carbon emissions over the next 40 years, likely allowing polluters in the United States to purchase carbon offsets from developing countries at a low cost. The high scenario assumes that carbon offsets are not allowed at all and the expansion of nuclear and biomass are restricted (Rushing et al., 2010). These three carbon pricing scenarios allow decision-makers to include potential future carbon pricing in their analysis of energy efficiency projects.

The emissions of GHGs pose a long-term environmental threat to the viability of the world economy, allowing economic damages to be quantified and discounted to present value to determine the economic impact of emissions. The potential future pricing of carbon dioxide is not likely to be based solely on these societal costs. Any carbon pricing or cap and trade scenario would also likely incorporate economic, political, and philosophical considerations into their implementation. While current greenhouse gas emissions have quantifiable long-term impacts, the emissions of non-GHG air pollutants have a more immediate, but less easily quantifiable, impact upon society. The next section will outline the methods by which the social costs of non-GHG pollutants are sometimes quantified.

Societal Costs of Non-Greenhouse Gas Air Pollutants

In addition to the concern regarding the emissions of greenhouse gases, there are a number of other air pollutants of concern resulting from the production of energy. Sulfur dioxide (SO_2) is a precursor to both acid rain and particulate matter in the air. Additionally, atmospheric sulfur dioxide can have human health as well as ecological impacts. Oxides of nitrogen (NO_x), specifically nitric oxide (NO) and nitrogen dioxide (NO_2), are byproducts of combustion that form as a result of the reaction of nitrogen and oxygen. NO_x can react with other compounds in the air to form particulate matter, which has a number of human health impacts. Additionally, NO_x can react to form nitric acid, which is a major component of acid rain. NO_x is also responsible for producing ground-level ozone, which has a number of human health effects, and destroying stratospheric ozone, which protects the planet from ultraviolet radiation. The quantification of the economic damages associated with emissions of these pollutants is fairly uncertain and relies on different methods than the quantification of damages associated with greenhouse gases.

According to Roth and Ambs (2004), damage costing "is highly complex, as it demands difficult judgments in the valuation of external effects such as damage to ecosystems, health impacts, and loss of human life." They outline another alternative costing method, control costing, which they claim is more straightforward. Control costing is based on the cost to control or clean up emissions, assuming that these are reasonable approximations of the economic damage done. Their study utilized control costing to determine the externalities of air pollutant emissions associated with electric power generation. The study provided best estimate values, lower range values, and

higher range values for the damage costs, in dollars per ton, of a number of pollutants, including SO_2 and NO_x. The best estimates are median values of the damage costs found in the literature and represent costs to install emissions reduction equipment. Lower and upper values represent a range of values consistently found in the literature, but are not the most extreme values found in the literature. The lower range values for SO_2 and NO_x provided in the study were $1636 and $1049, respectively; the median estimates were $1870 and $7919; and the upper range estimates were $4934 and $10,031.

While the emissions of air pollutants are a significant environmental concern, many people face immediate shortages of a natural resource that is crucial to their survival – water. Many people in developed nations take water for granted due to its availability and affordability; however, there are many people throughout the world who do not have sufficient water. Additionally, the collection, treatment, and eventual disposal of water resources have large direct, opportunity, and environmental costs. Many of these costs are not factored into the price paid by consumers to the local water utility, encouraging overconsumption. Consideration of the full costs of water can allow more informed investment decisions to be made when water use is a factor.

Full Cost of Water

Water is vital to human survival, yet it is a natural resource that tends to be underpriced and over consumed. In the past, water has been considered a renewable resource and has therefore been priced fairly low. Stallworth (2000) argues,

> Recent experience has brought the more sobering insight into the hydrological cycle: that water cannot be treated as a perfectly renewable resource. Withdrawals from our watersheds for drinking and industrial water and subsequent wastewater treatment are processes that, at today's scale, have large 'unpriced' external

> effects: land use consequences, biological degradation, and water quantity depletion. In view of these encroaching resource limits, it is important to begin considering how to translate these causal relationships through the price mechanism to reflect the underlying ecological costs to society.

Stallworth (2000), among many others, argues for the use of full cost pricing to factor the supply costs, opportunity costs, and externalities of water. According to her, "'Full costs' refers to the complete societal costs (environmental, social, and actual) that pertain to the production and consumption of a good or service. Economics shows us that social welfare is maximized when all costs are reflected in prices. This is sometimes referred to as 'full cost pricing' or the 'polluter pays principle'." Rogers et al. (2002) agree that full-cost pricing can encourage more sustainable use of water and state "Water pricing can improve economic efficiency and improve social equity, and by using less of the resource more efficiently, lead to environmental enhancement." Figure 1 shows the elements of the full-cost of water, as defined by Rogers et al. (1998). They further argue that the full-cost should just equal the sustainable value in use in order for water to be allocated most efficiently within the economy. The full supply cost represents the cost required to provide water to consumers. The opportunity cost of water is the cost associated with the loss of the ability to use water for a specific function when it is used in another. An example is the loss of the use of water for recreational purposes if it is reserved for drinking water. The full cost of water varies across different regions and different municipalities due to the scarcity of water and the cost to supply water in different cities. Arpke and Strong (2005) performed a life-cycle cost analysis of various water efficiency alternatives for a college dorm in different cities, comparing the results of analysis using full-costs and subsidized costs of water.

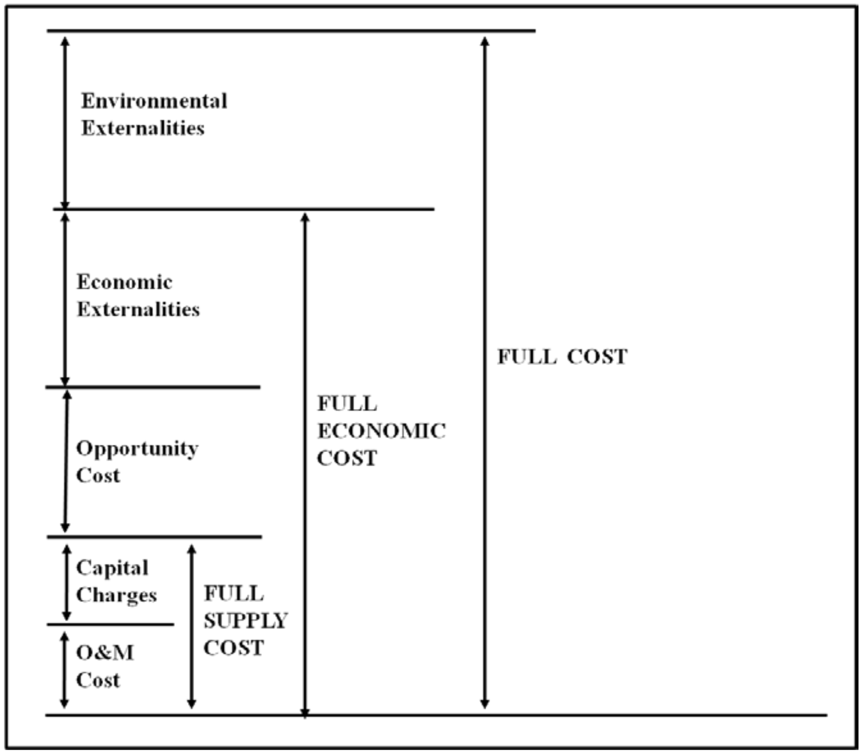


Figure 1. General Principles for Quantifying Cost of Water (Rogers et al., 1998)

Arpke and Strong (2005) define the full-cost of water slightly differently than Stallworth (2000) or Rogers et al. (1998). They define the full-cost pricing of water as “an attempt to represent the true *market* value of the water to decision makers when designing and developing the built environment.” They also acknowledge that there are external non-market factors including “aesthetics, environmental sustainability, impact on ecosystem health, etc., that are not captured in an economic decision model.” For the purposes of their study, they appear to define “full-cost” similar to the “full supply cost” as defined by Rogers et al. (1998). Therefore, the full cost used in their study does not include opportunity costs or externalities.

The central premise of their study is a comparison of the life-cycle cost-effectiveness of water efficiency measures under the full cost and under the price frequently paid for water, which is generally below the full supply cost of water. Arpke and Strong (2005) identify three common forms of market imperfections that affect the efficient allocation of water resources. These are:

> (1) capital subsidies in the form of infrastructure grants and low interest loans, (2) operating subsidies in the form of revenue transfers from other sources (e.g., property taxes) and (3) "future faith and credit" assumptions resulting from the failure to include recapitalization expenses for future infrastructure needs within present water rate structures.

The study found that basic water efficiency measures (high-efficiency water fixtures) were cost effective even under subsidized pricing of water, but that greywater (wastewater that does not contain human waste) recycling became cost effective in one of the four cities studied (Houghton, Michigan) under full-cost pricing of water. The study attempted to factor the deferred maintenance costs and the total supply cost in the various cities when calculating the full cost of water. This demonstrates that full-cost pricing of water can change water efficiency decisions in built infrastructure. It is difficult to say how these results would have changed had the full-cost pricing been used as Rogers et al. (1998) define it. It is possible that greywater recycling may have become cost effective in more cities.

Despite the availability of fairly sophisticated methods to determine both the direct costs and full costs associated with facility projects, these values exhibit a great deal of uncertainty. Direct costs are fairly certain in the short term, but their uncertainty increases in the future as a result of uncertain operations and maintenance costs as well as uncertainty in the useful life of assets. Environmental costs are fairly uncertain, even in

the short term, due to the extremely complex and interconnected nature of the natural world. In order to account for some of this uncertainty, Monte Carlo simulation can be used to evaluate the range and expected value of life-cycle costs, thus giving the decision-maker greater understanding of the uncertainty involved in the economic analysis.

Handling Uncertainty Using Monte Carlo Simulation

The use of simulation in capital investments is often traced back to an article by Hertz in the Harvard Business Review in 1964. Simulation allows a decision-maker to account for some of the uncertainty in variables that are used in an economic analysis. Davis (1995) defines stochastic simulation as “a rigorous computational method of project valuation that takes input parameter uncertainty into account. In a stochastic simulation, each uncertain variable is input as a probability distribution that reflects the variable’s uncertainty.” Hertz (1964) argues for the importance of simulation by noting that each assumption in a capital investment decision has a high degree of uncertainty, and these uncertainties multiplied together can lead to uncertainty of “critical proportions.” He outlines the three steps required to complete a stochastic simulation:

1. Estimate the range of values for each of the factors (e.g., range of selling prices, sales growth rate, and so on) and within that range the likelihood of occurrence of each value.
2. Select at random from the distribution of values for each factor one particular value. Then combine the values for all of the factors and compute the rate of return (or present value) from that combination…

3. Do this over and over again to define and evaluate the odds of the occurrence of each possible rate of return. Since there are literally millions of possible combinations of values, we need to test the likelihood that various specific returns on the investment will occur…

Simulations are frequently run in spreadsheet software packages, where random numbers can be generated to randomly select values from the probability distributions. The result of the simulation is a probability density function of the possible values of the variable of interest, which is frequently the net present value or internal rate of return. The expected value of the output parameter is the average of the values of all outcomes weighted by the probability of occurrence (Hertz, 1964). While it is helpful for decision-makers to understand the range of possible values that the variable of interest may take on, it does not remove all risk from the decision. Davis (1995) states that some decision-makers reduce the discount rate for their analysis based on the belief that more risk is handled by the simulation; therefore, the discount rate does not need to account for this risk. He argues that this logic is incorrect and that simulation merely gives the decision-maker a better understanding of the uncertainty involved in the analysis, but does not reduce their risk. Gluch (2004) downplays the use of simulation in reducing uncertainty by stating "these techniques presuppose that decision makers are aware of the nature of the uncertainties that can be expected during the building's lifetime." Simulation appears to be a powerful tool that can help the decision-maker handle some of the risk in capital budgeting, but cannot remove all risk from the decision-making process. The use of simulation at least provides the decision-maker with a better characterization of the risk involved in a decision.

III. Methodology

This chapter reviews the methods employed to develop a probabilistic life-cycle full-cost analysis tool for use with Energy Conservation Investment Program (ECIP) projects. The chapter begins with an explanation of the development of the tool. The method of calculating life-cycle costs and life-cycle air pollutant emissions are then outlined. The basic financial measures of simple payback period (SPB), savings-to-investment ratio (SIR), Btu-to-investment ratio (BIR), CO_2-to-investment ratio (CIR), and adjusted internal rate of return (AIRR) are also defined. The inclusion of Monte Carlo simulation to handle uncertainty is then discussed. Finally, the chapter provides an overview of the ECIP project analysis accomplished with the tool.

Development of Probabilistic Life-Cycle Full-Cost Analysis Tool

A probabilistic life-cycle full-cost analysis tool was developed based on the methods outlined in the National Institute of Standards and Technology (NIST) Handbook 135 for energy and water efficiency projects. The tool was designed to allow a user to input values from the Building Life-Cycle Cost (BLCC) program ECIP Report and perform additional analysis, including incorporation of the externalities of energy use and performance of a Monte Carlo simulation. During the development of the tool, it was decided to not consider the full cost of water use when calculating social benefits. This decision was made because accurate calculation of the full cost of water requires consideration of a large number of factors that the average decision-maker would not have sufficient information to consider, such as the maintenance backlog on the local

water system and the scarcity of water in that particular region at that particular time. Additionally, the decision was made to tailor the probabilistic life-cycle full-cost analysis tool to energy-efficiency projects, specifically the ECIP program. The tool considers the environmental externalities of energy use through the use of the social cost of air pollutants emitted as a result of energy generation.

Determination of Social Cost of Carbon Dioxide

The tool was designed to allow user input of the social cost of carbon dioxide (CO_2), sulfur dioxide (SO_2), and oxides of nitrogen (NO_x); however, default values are provided in the tool. The default values of the social costs of greenhouse gases were determined by a review of literature. The U.S. Interagency Working Group on Social Cost of Carbon (2010) provided values of the social cost of carbon (SCC) under various discount rates starting in the year 2010 and proceeding until year 2050. The social cost of carbon for the 3% discount rate was used because this is the discount rate currently recommended by NIST Handbook 135 as the market discount rate. Based on a discount rate of 3%, the social cost of carbon dioxide was \$21.40 per metric ton of CO_2 in 2010 and \$44.90 per metric ton of CO_2 in 2050 (in constant 2007 dollars). This represents an average rate of increase of 1.87% per year. In order to be used in the probabilistic life-cycle full-cost analysis tool, the social cost of carbon dioxide for the base year of the project was first calculated by escalating the 2010 value of the SCC at 1.87% for the annual increase in the cost and then bringing the SCC to current dollars for the base year of the project using an assumed average inflation rate of 0.9%. In order to account for the large amount of uncertainty in this value, the social cost of carbon was assumed to

represent a triangular probability distribution bounded by the mean values of the three Integrated Assessment Models used in the Interagency Working Group report. The FUND model returned a mean value for the SCC of $6.00 per metric ton and the PAGE model returned a mean value of $29.80 per metric ton of CO_2, both for a 3% discount rate. These were used as the minimum and maximum values of the triangular distribution.

Determination of Social Cost of Non-Greenhouse Gas Air Pollutants

Roth and Ambs (2004) provided estimates for the damage costs of several air pollutants, including sulfur dioxide and oxides of nitrogen, for the calculation of externalities associated with energy generation. They provided lower range, best estimate, and upper range values for the control costs of these pollutants. These values can be found in the literature review. For the purposes of this research, the lower range values of $1636 and $1049 for SO_2 and NO_x, respectively, were used as the default social costs of these pollutants in the life-cycle full-cost analysis tool. These values were assumed to be constant and were therefore not modeled by a probability distribution. Additionally, they were assumed to increase at the rate of inflation and therefore were assigned escalation rates of zero.

Calculation of Air Pollutant Emissions

Air pollutant emissions were calculated using emissions factors for each type of pollutant and each energy type. The four energy types considered within the life-cycle full-cost analysis tool are electricity, natural gas, distillate fuel oil (#1, #2), and liquefied petroleum gas. Each energy type has an emissions factor, in metric tons pollutant per million British Thermal Units (MBtu). The emissions factors for natural gas, distillate

fuel oil (#1, #2), and liquefied petroleum gas used in the life-cycle full-cost analysis tool were the same as those found in the BLCC program. These emissions factors are summarized in Table 2. Emissions factors for electricity were provided by the Environmental Protection Agency (EPA) Emissions and Generation Resource Integrated Database (eGRID). The U.S. Average emissions factors for electricity can also be found in Table 2.

Table 2. Emissions Factors by Energy Type (metric tons pollutant / MBtu energy)

	Natural Gas	**Distillate Fuel Oil (#1, #2)**	**Liquefied Petroleum Gas**	**Electricity (US Average)**
Assumed Generation Method in BLCC	Commerical boiler, controlled low NOx burner	Industrial / Commerical Boiler	Commerical Boiler	N/A
CO_2	0.05285	0.07262	0.06277	0.17275
NO_x	0.00001	0.00007	0.00007	0.00024
SO_2	0.00043	0.00052	0.00051	0.00063

The EPA eGRID database includes emissions data for electricity production in each state as well as the average for the entire United States. The most recent version of the database, eGRID2010 Version 1.1, is the seventh edition and contains year 2007 data on air pollutant emissions. The life-cycle full-cost analysis tool allows the user to select the state in which the project is located from a dropdown menu and uses this information to calculate emissions factors for CO_2, SO_2, and NO_x. Therefore, the reduction in pollutants resulting from energy use reductions can be estimated. The emissions factors from the eGRID database, in pounds of pollutant per megawatt-hour of electricity, can be found in Appendix C. These factors were then converted to metric tons of pollutant per MBtu using the following equation:

$$EF\ [metric\ tons/MBtu] = EF\ [lb/MWh] \times \frac{1\ metric\ ton}{2204.62\ lb} \times \frac{1\ MWh}{3.413\ MBtu}$$

Additionally, the tool incorporates the appropriate grid loss factor for each electrical grid within the United States and factors this into the calculation of the primary electricity production required to provide electricity to the consumer. The primary electricity production is used to calculate the emissions associated with energy use reductions and is calculated using the following equation:

$$PEP = ER\ \times (1 + (GL \div 100))$$

where *PEP* is the Primary Electricity Production Reduction (in MBtu), *ER* is the electricity use reduction (in MBtu), and *GLF* is the grid loss factor, expressed as a percent. The next section will outline the calculations used within the tool to determine the life-cycle costs of the project.

Life-Cycle Cost Calculations

In order to compare life-cycle project costs occurring over many years, the costs must be discounted back to a common time period. The tool developed for this research was designed to calculate the net present value of future costs and benefits, which is then used to calculate a number of supplemental financial measures that allow comparison of the cost-effectiveness of individual projects.

The NIST BLCC program uses factors to discount one-time future and annually recurring values back to present value. In order to remain consistent with the NIST methodology for determining discount factors, this tool allows the user to enter the

discount factor provided by the BLCC program, which is based on the timing, frequency, and nature of the future cost. For example, energy costs are assumed to increase over time by a certain non-constant escalation rate. The annual supplement to NIST Handbook 135 provides discount factors for energy costs that incorporate this price escalation as well as the correct discount rate for the current year. These values are programmed into the BLCC program, allowing users to avoid the difficulty of finding these discount factors in the annual supplement to NIST Handbook 135. The probabilistic life-cycle full-cost analysis tool developed for this research allows the user to enter the discount factors determined by the BLCC program so that the calculated life-cycle costs within the life-cycle full-cost analysis tool are consistent with those provided in the ECIP report of the BLCC program.

NIST Handbook 135 and the BLCC program use the modified uniform present value (UPV*) energy cost escalation factor to calculate the present value of a future stream of energy prices adjusted for expected changes in energy prices. The UPV* factor is a function of the project region, project fuel type, rate type, discount rate, and number of years of project life. Current values for the UPV* factor are found in the annual supplement to NIST Handbook 135; however, the BLCC program automatically determines the value of the UPV* factor to use based on the features of the project. The present value of annually recurring non-uniform energy costs escalated at a non-constant rate can be calculated using the following formula:

$$PV = A_0 \times UPV^*_{(reg,ft,rt,d,n)}$$

where *PV* is the present value (in dollars), A_0 is the current energy rate (in dollars per MBtu), and *UPV** is the modified uniform present value factor, which is a function of region, fuel type, electricity rate type, discount rate, and the number of years over which the annual cost occurs. The probabilistic life-cycle full-cost analysis tool developed for this research requires input of the UPV* factor, which is determined by the BLCC program and provided in the ECIP report.

For benefits and costs not included in the BLCC program, namely the social benefits of energy use reductions, the life-cycle full-cost analysis tool discounts these values based on the standard discount rate provided in the ECIP report. The social costs of SO_2 and NO_x were assumed to remain constant over the life of the project, allowing calculation of the present value of these benefits using a standard present value formula. The present value of the annually recurring constant social costs of SO_2 and NO_x were calculated using the following formula:

$$PV = A_0 \times \sum_{t=1}^{n} \frac{1}{(1+d)^t} = A_0 \times \frac{(1+d)^n - 1}{d(1+d)^n}$$

where *PV* is present value (in dollars), A_0 is the annual social benefit of emissions reductions (in dollars), d is the discount rate, and n is the number of years over which the annual cost occurs. This formula was executed in Microsoft Excel using the PV function, where the annual environmental benefit, discount rate, and economic life were entered as arguments for the function. The amount of the uniform annual social cost, A_0, was calculated as follows:

$$A_0 = \sum_i SC_i \sum_j ES_j \times ER_{ij}$$

where A_0 is the annual social benefits of emissions reductions (in dollars), SC_i is the social cost of pollutant i (in dollars per metric ton), ES_j is the annual usage savings of energy type j (in MBtu), and ER_{ij} is the emission rate for pollutant i of energy type j (in metric tons pollutant per MBtu).

While the social costs of SO_2 and NO_x were assumed to remain constant over the life of the project, the social cost of CO_2 was assumed to increase at a standard annual escalation rate of 1.87%. This value was calculated based on the social costs of carbon dioxide found in the Interagency Working Group on Social Cost of Carbon report. The following formula was used to calculate the present value of the annually recurring non-uniform social cost of carbon dioxide:

$$PV = A_0 \times \sum_{t=1}^{n} \left(\frac{1+e}{1+d}\right)^t = A_0 \times \frac{(1+e)}{(d-e)}\left[1 - \left(\frac{1+e}{1+d}\right)^n\right]$$

where PV is the present value (in dollars), A_0 is the social benefit of emissions reductions in the base year of the project (in dollars), d is the discount rate, e is the constant escalation rate of the social cost, and n is the number of years over which the annual cost occurs.

The present value equation for the annually recurring uniform social costs of SO_2 and NO_x as well as the equation for the annually recurring non-uniform social cost of CO_2, use the end-of-period discounting convention. Because the Department of Defense

uses the mid-period discounting convention for ECIP projects, the present values calculated using the equations presented above had to be adjusted for the change in discounting convention. The present values calculated using end-of-year discounting had to be discounted forward a half year to be consistent with mid-period discounting. This adjustment was calculated using the following equation:

$$PV_{Mid} = PV_{End} \times (1 + d)^{0.5}$$

where PV_{Mid} is the present value based on mid-period discounting, PV_{End} is the present value based on end-of-period discounting, and d is the discount rate. This was executed using the FV function in Excel, where the present value from end-of-year discounting, discount rate, and number of periods of 0.5 were entered as arguments for the function. Following the calculation of the present value of future costs and benefits, a number of supplemental financial measures were calculated. These measures assist in the prioritization of energy efficiency projects on the basis of return on investment.

Calculation of Supplemental Financial Measures

NIST Handbook 135 outlines a number of supplemental financial measures; however, this research focuses on the measures provided in the Energy Conservation Investment Program (ECIP) Report from the Building Life-Cycle Cost (BLCC) tool. These measures are simple payback (SPB), savings-to-investment ratio (SIR), and adjusted internal rate of return (AIRR). Additionally, the Air Force prioritizes ECIP projects utilizing the Btu-to-investment ratio (BIR), which will also be defined. This

section will conclude with the definition of another metric developed for this research, the CO_2-to-investment ratio (CIR).

Simple Payback

Simple payback (SPB) is a measure of the time required to recover initial investment costs. SPB is expressed as the number of years from the beginning of the service period to the time at which all capital costs have been recovered. When calculating simple payback, unlike when calculating discounted payback, future costs are not discounted nor are annual price escalations considered; the total initial investment is simply divided by the first-year savings of the project. Simple payback has the drawback of ignoring any costs or savings realized after the break-even point. The probabilistic life-cycle full-cost analysis tool provides values of the SPB for each project, but simple payback is not used in the ranking of ECIP projects and will therefore not be discussed further in this research.

Savings-to-Investment Ratio

The savings-to-investment ratio (SIR) is a measure of economic performance that expresses the relationship between a project's savings and its increased present value investment costs. It is a variation on the Benefit-Cost ratio; the benefits are the present value of cost savings associated with energy and water use reductions, and the costs are the present value of all life-cycle costs associated with the project. The formula for calculating the SIR is as follows:

$$SIR = \frac{\Delta E + \Delta W + \Delta OM\&R + \Delta SB}{I_0}$$

where *SIR* is the savings-to-investment ratio, ΔE is the present value of annual energy cost savings, ΔW is the present value of annual water cost savings, $\Delta OM\&R$ is the present value of annual operations, maintenance, and repair cost savings, ΔSB is the present value of annual social benefits of reduced pollutant emissions, and I_0 is the total initial investment.

Adjusted Internal Rate of Return

The adjusted internal rate of return (AIRR) is a measure of the annual percentage yield over the life of the project. The AIRR should be compared to the investor's minimum attractive rate of return (MARR) to determine whether a project is worth the investment cost. The AIRR assumes that all cost savings can be reinvested at the MARR. The most direct way to calculate the AIRR for a project is to calculate it from the SIR based on the following formula:

$$AIRR = (1 + d) \times (SIR)^{\frac{1}{n}} - 1$$

where *AIRR* is the adjusted internal rate of return, *d* is the discount rate, *SIR* is the savings-to-investment ratio, and *n* is the economic life of the project. The probabilistic life-cycle full-cost analysis tool calculates the AIRR for each project, but because this value is not used in the ranking of ECIP projects it will not be discussed further in this research.

Btu-to-Investment Ratio

The Btu-to-investment ratio (BIR) is calculated as the ratio of the annual energy savings (in MBtu) attributed to the project to the total initial investment of the project. It is a measure of the energy savings from the project relative to the investment required.

For prioritization of ECIP projects, the BIR is multiplied by the SIR for each project and a score is determined that is used to rank projects. The probabilistic life-cycle full-cost analysis tool calculates the BIR and the ranking score for each project. Additionally, the BIR is calculated for each iteration in the Monte Carlo simulation to develop a probability distribution of the BIR.

<u>CO_2-to-Investment Ratio</u>

As part of this research, another measure was created to account for greenhouse gas emissions reductions associated with the energy use reductions of a project. The CO_2-to-Investment Ratio (CIR) is calculated as the ratio of the annual carbon dioxide emissions reductions (in metric tons) to the total initial investment of the project. It is a measure of the carbon dioxide emissions reductions resulting from energy use reductions of a project relative to the investment required. The CIR is not currently used in the prioritization of ECIP projects; however, this research investigated the potential influence of the CIR on ECIP project prioritization. The probabilistic life-cycle full-cost analysis tool calculates the CIR and a ranking score for each project, which is calculated as the product of the SIR and the CIR. Additionally, the CIR is calculated for each iteration in the Monte Carlo simulation to develop a probability distribution of the CIR. The next section will outline the steps taken to incorporate Monte Carlo simulation into the probabilistic life-cycle full-cost analysis tool.

Monte Carlo Simulation

The preceding section outlined the steps taken to calculate life-cycle costs and supplemental financial measures for an individual project. The inputs to these equations represent estimates of the actual project parameters, including initial cost, operations and maintenance costs, energy and water usage savings, and project lifetime. These values are more uncertain than the use of single value estimates would suggest. The use of these single value estimates (i.e., point estimates) for project parameters provides the decision-maker with a deterministic value for the life-cycle costs of the project as well as the supplemental financial measures, when in actuality the true costs are virtually guaranteed to differ from these estimates. To account for the uncertainty inherent in the input parameters, the life-cycle full-cost analysis tool was developed to utilize Monte Carlo simulation to model the possible values that the life-cycle costs and supplemental financial measures could take.

The user of the probabilistic life-cycle full-cost analysis tool is able to select between a constant value, a triangular probability distribution, or a normal probability distribution for a number of variables – namely total investment, annual energy usage reductions, and the social cost of CO_2. Although the user has the option to establish the parameters of each probability distribution (minimum, mode, and maximum for the triangular distribution and mean and standard deviation for the normal distribution), the default values are provided. The expected value for each input variable is provided by the user and the parameters which characterize the probability distribution are calculated by the tool based on percentage deviation from the expected value.

The default minimum and maximum values for the Total Investment were assumed to be 85% and 150% of the expected value, respectively; for the annual electricity, natural gas, and distillate fuel oil usage, the minimum and maximum were 85% and 115%, respectively. The uncertainty in the social cost of carbon dioxide was modeled by a triangular distribution with the mode being the mean value of the three integrated assessment models provided by the Interagency Working Group on Social Cost of Carbon, the minimum being the mean value provided by the FUND model in the same study, and the maximum being the mean value provided by the PAGE model in the same study. Once the input probability distributions are characterized, the tool performs a Monte Carlo simulation using 1,000 iterations. Life-cycle costs and supplemental financial measures are calculated during each iteration. The tool outputs probability densities and expected values of the supplemental financial measures, both with and without the environmental benefits of emissions reductions factored in. The tool produces a report formatted like the BLCC ECIP Report that provides both deterministic and probabilistic values of supplemental financial measures.

Sensitivity Analysis

The tool was developed to provide a sensitivity analysis of the SIR and AIRR to the decision-maker based on percentage deviation of input parameters. The sensitivity analysis is presented as a graph of the percentage deviation of each variable versus the SIR or AIRR associated with that percentage variation. The input variables included in the sensitivity analysis are total investment, energy savings, non-energy savings/costs, and the social costs of pollutants. The variation of each variable ranges from -20% to

+20% of the deterministic value. In order to complete a sensitivity analysis, a single input parameter is varied by a fixed percentage and the financial measures are calculated for that given variation. This is repeated for different percentage variations and each different variable. This sensitivity analysis allows the decision-maker to determine how variation in a single input parameter affects the SIR or AIRR. Additionally, it allows the decision-maker to determine which variables have the largest influence on the supplemental financial measures and therefore better determine which variables require the most accurate estimation.

Solicitation of Feedback on Tool Development

In an effort to make the probabilistic life-cycle full-cost analysis tool more useful to decision-makers, a preliminary version was sent to several Air Force members for feedback on the operation and functionality of the tool. Feedback was provided by a member of the Air Force Civil Engineer Support Agency (AFCESA) who oversees the ECIP program for the Air Force, an Air Force Major Command energy analyst, a base-level energy manager, a base-level mechanical engineer, and an Air Force Center for Engineering and the Environment (AFCEE) air quality subject matter expert. A sample of the feedback questionnaire and a summary of the feedback provided can be found in Appendix D. The feedback provided by these users was incorporated into the final versions of both the probabilistic life-cycle full-cost analysis tool and the tool's associated user guide, which can be found in Appendix B. Following the development of the probabilistic life-cycle full-cost analysis tool, several projects from the FY12 ECIP

program were analyzed in order to demonstrate the functionality of the tool and investigate any additional insights it provides to decision-makers. The steps utilized to perform this analysis are outlined in the next sections.

Project Data Acquisition

This research involved the analysis of several projects from the FY12 ECIP program. The packages for the specific projects analyzed in this research were obtained from AFCESA. These packages were submitted to AFCESA by base-level energy managers for project funding under the ECIP program. The packages include the DD Form 1391 as well as the ECIP report from the BLCC program. The projects analyzed in this research were the top ten Air Force projects from the FY12 ECIP program. Additionally, six projects from the bottom ten ranked ECIP projects from the FY12 program were analyzed.

Statistical Comparison of SIR Including and Excluding Social Benefits

Inclusion of the social benefits of air pollutant emissions reductions in life-cycle cost analyses is expected to increase the SIR of energy efficiency projects. In order to determine whether the inclusion of the social benefits of air pollutant emissions reductions has a statistically significant impact on the calculated SIR, a two sample t-Test was used. Probabilistic model results that included social benefits of emissions reductions were compared with results that excluded the social benefits. The expected value of the social costs of carbon dioxide, oxides of nitrogen, and sulfur dioxide were varied and t-Tests performed to determine the minimum values of the social costs that would have a statistically significant influence on the project's SIR. A significance level of 0.05 was

used for each t-Test. For each test, all social costs besides the one of interest were assumed to be zero and all escalation rates were zero. Because the AIRR is not used for ranking of ECIP projects, a statistical comparison was not performed on the AIRR.

Sensitivity Analysis of SIR to Variation in Input Parameters

The supplemental financial measures used to prioritize ECIP projects can vary a great deal based on variation in a number of input parameters. The probabilistic life-cycle full-cost analysis tool was used to perform a sensitivity analysis on several ECIP projects to determine the influence of various input parameters on the SIR. The specific input parameters varied in this research were total investment, energy usage, social cost of air pollutants, and energy type. For the sensitivity analysis of SIR to total investment, energy usage, and social cost of air pollutants, the expected values were varied between -20% and +20%. For the sensitivity of the SIR to energy type, the annual energy usage savings remained constant, but the distribution of usage savings amongst each type of energy was varied to determine the impact of changes in emissions on the SIR.

Comparison of Deterministic and Probabilistic Results

Projects are currently prioritized for funding under the ECIP program utilizing the deterministic values of the supplemental financial measures that are calculated by the BLCC program. These deterministic values fail to account for the uncertainty inherent in each of the input parameters and therefore the uncertainty in the supplemental financial measures. Several ECIP projects were analyzed to compare the deterministic values of the SIR to the probability distribution generated by the probabilistic life-cycle full-cost analysis tool. The assumptions used for the underlying probability distributions of input

parameters were those presented in the Monte Carlo Simulation section of this chapter. Each project analyzed was input into the tool and the simulation was performed to generate a probability distribution of the SIR. This probability distribution was then compared with the deterministic value to determine the probability of the supplemental financial measures exceeding the deterministic value. Additionally, the probability distribution was used to determine the probability of the supplemental financial measure exceeding the threshold value for funding of the project.

Effect of Social Cost and Uncertainty on Ranking of ECIP Projects

Air Force Energy Conservation Investment Program (ECIP) projects for a given fiscal year are currently ranked by a score derived from the multiplication of the SIR and the Btu-to-investment ratio (BIR). Funding is allocated to the projects in rank order until no further funding is available. This research sought to determine whether the inclusion of the social benefits of air pollutant emissions reductions affects the rank order of projects. In order to determine the impact of the inclusion of the social benefits on the rank order of projects, the SIR for each project was calculated for the top ten ranked Air Force projects in the FY12 ECIP program under a number of different conditions. The SIR was calculated based on deterministic and probabilistic values, both including and excluding social benefits of emissions reductions. The mean and 95th percentile values of the probability distribution of the SIR were reported. The various values of the SIR were then multiplied by the BIR, both deterministic and probabilistic, to determine a ranking score and an associated project ranking. Additionally, the ranking of projects based solely on SIR was determined. Finally, the ranking of projects based on the product of the SIR

and CIR, both deterministic and probabilistic, was determined. The rankings under each of these different scenarios were then compared to determine whether the rank order was affected by differing ranking schemes.

Summary

This chapter outlined the development of a probabilistic life-cycle full-cost analysis tool that calculates the environmental benefits of air pollutant emissions reductions resulting from Energy Conservation Investment Program (ECIP) projects. The tool is meant to be used in conjunction with the NIST BLCC program, which performs a deterministic life-cycle cost analysis on ECIP projects. The probabilistic life-cycle full-cost analysis tool accepts as input the results of the BLCC program and completes a Monte Carlo simulation based on assumed probability distributions of input parameters. The tool additionally provides a sensitivity analysis of the supplemental financial measures of Savings-to-Investment Ratio (SIR) and Adjusted Internal Rate of Return (AIRR) based on fixed percentage variations of input parameters. The life-cycle full-cost analysis tool was then used to analyze several projects from the FY12 ECIP program. Several projects were analyzed to determine whether the inclusion of the social cost of air pollutants had a statistically significant impact on the SIR. Sensitivity analyses were also completed on several of the projects based on varying the expected values of input parameters. The tool was used to compare the deterministic values of the supplemental financial measures with the probability distributions of the same variables. Finally, the effect of the inclusion of the social benefits of air pollutant emissions reductions and the use of Monte Carlo simulation on the ranking of ECIP projects was investigated.

IV. Results

This chapter details the results of analyses accomplished with the probabilistic life-cycle full-cost analysis tool developed during this research and then applied to Energy Conservation Investment Program (ECIP) projects from the Fiscal Year 2012 (FY12) program. The chapter begins with a summary of the project data used to perform the analysis. Next, the results of a statistical comparison of the savings-to-investment ratio (SIR), including and excluding the social benefits of air pollutant emissions reductions, are presented. The results of the sensitivity analysis of the SIR for several projects are then outlined. Next, the deterministic and probabilistic results of life-cycle cost analyses on several ECIP projects are compared. Finally, the last section of the chapter compares ECIP project rankings under several different scenarios.

Summary of Project Data

The probabilistic life-cycle full-cost analysis tool was used to analyze several projects from the FY12 ECIP program. The project data were provided by the Air Force Civil Engineer Support Agency (AFCESA) in the form of project submission packages, which included the ECIP report output from the National Institute of Standards and Technology (NIST) Building Life-Cycle Cost (BLCC) tool. Additionally, a spreadsheet was provided that contained the SIR, Btu-to-investment ratio (BIR), ranking score for each project, and the ranking of the projects. The ten highest ranked projects in the FY12 program were analyzed, both independently and in aggregate to determine the effect of different ranking schemes. Additionally, six of the bottom ten ranked projects were

analyzed. These six projects were selected due to the availability of economic analyses. The remaining four projects from the bottom ten were not analyzed because economic analyses for these projects were not available. The 16 projects analyzed for this research are shown in Table 3. For simplicity, the project number will be used to identify each project in the remainder of this chapter. Full details of the project data can be found in Appendix E.

Table 3. Summary of ECIP Project Data

Installation	Project Title	Project Number
Aviano AFB	Renewable: Install Photovoltaic Panels For The BX	ASHE121005
Cannon AFB	HVAC Modifications	CZQZ118002
Edwards AFB	ECIP HVAC Sys Multi	FSPM102214
Edwards AFB	Rpr Water Tank And Piping To B4980	FSPM091286
Fort Dix	Upgrade Lighting Humidity Control Warehouse, Bldg 3351	HEKP124000
FE Warren AFB	ECP-Leak Detection/Repair Natural Gas Distribution System	GHLN117005
Kirtland AFB	Repair HVAC Audited Facilities, KAFB	MHMV110059
Kirtland AFB	Repair Master Landscape Irrigation System, Basewide	MHMV100072
Langley AFB	HVAC Modifications In Multiple Facilities	MUHJ114017
Malmstrom AFB	Install Destratification Fans, Bldg 1440,1450,1460,1464	NZAS110301
Moody AFB	Rpr/Rpl Environmental Controls, Mult Facs	QSEU122014
Moody AFB	Rpr/Rpl Boilers/Hot Water Sys, Multi Facs	QSEU122012
Offutt AFB	Rpr Steam Traps, B500, B501, B515	SGBP120038
Ramstein AFB	Energy Cons: Hangar Heating Controls & Door Seals	TYFR121135
Ramstein AFB	Renewable: Construct PV Power Generation	TYFR101089
Robins AFB	Rpr/Rpl Steam Traps, Htg Fclty Bldg, B/177	UHHZ110225

Results of Statistical Analysis of SIR

A statistical analysis was accomplished to determine the impact of including the social benefits of air pollutant emissions reductions on the savings-to-investment ratio (SIR). A two-tailed t-Test was used to determine whether there was a statistical difference between the SIR from two samples; one sample consisted of probabilistically-

calculated values of the SIR that included social benefits and the other sample consisted of probabilistically-calculated values of the SIR that excluded social benefits. Each sample contained 1000 data points and the samples were assumed to have unequal variance. In order to generate each sample, the parameters of total investment and energy savings were varied based on the assumptions presented in the Methodology chapter. The social costs of all pollutants were assumed to be deterministic, and therefore were not modeled probabilistically. Additionally, the escalation rate for all social costs was assumed to be zero. Table 4 shows the results of the statistical analysis for the social cost of each pollutant. In order to determine the minimum statistically significant value of the social cost for each pollutant, the social cost of all other pollutants was set to zero and the social cost of the pollutant of interest was increased until the p-value of the t-Test was 0.05 or less. The number reported is the lowest whole dollar value of the social cost (in dollars per metric ton of pollutant) of that pollutant that has a statistically significant influence on the SIR.

Table 4. Results of Statistical Analysis of SIR

Project Number	Total Investment	Energy Savings (MBtu)	Percentage of Energy Savings by Type				Min Value of SC ($/metric ton) for P-Value ≤ 0.05		
			Elec	NG	DFO	LPG	Social Cost of CO_2	Social Cost of NO_x	Social Cost of SO_2
UHHZ110225	$112,000	38760		100.0%			$1	$4,707	$110
SGBP120038	$375,067	47724		100.0%			$3	$11,428	$266
MHMV110059	$661,800	38925	53.5%	46.5%			$2	$537	$524
QSEU122014	$125,400	11135	7.0%	93.0%			$2	$2,874	$146
MUHJ114017	$640,961	36887	29.4%	70.6%			$2	$1,380	$222
TYFR121135	$428,740	12282	19.4%	68.1%	12.5%		$4	$4,896	$650
QSEU122012	$1,804,000	69786	0.7%	99.3%			$2	$6,622	$176
NZAS110301	$128,000	2926	100.0%				$2	$608	$610
CZQZ118002	$526,247	16371	37.9%	62.0%		0.1%	$1	$457	$288
GHLN117005	$266,800	11209		100.0%			$2	$9,313	$217
HEKP124000	$113,000	199	100.0%				$6	$1,811	$1,449
ASHE121005	$118,000	103	100.0%				$5	$3,598	$1,358
TYFR101089	$580,000	410	100.0%				$9	$6,050	$2,284
FSPM102214	$3,500,000	6930	83.1%	16.9%			$9	$14,009	$5,439
FSPM091286	$121,118	45	100.0%				$43	$61,707	$58,434
MHMV100072	$149,200	141	100.0%				$8	$3,307	$8,909
Actual Social Cost Values Used in This Research:							$21	$1,049	$1,636

The threshold of statistical significance for the social cost of CO_2 was fairly low, usually in the range of \$1 – \$9. The exception is project number FSPM091286, which has a threshold value of \$43 per metric ton of CO_2. This project had a very low energy usage reduction of only 45 MBtu. The majority of the operational cost savings in this project came from water usage reductions. Therefore, the energy use reductions of the project avoided very few CO_2 emissions, thus requiring a higher social cost of CO_2 in order for the difference to be statistically significant. The actual value of the social cost of CO_2 used in the probabilistic life-cycle full-cost analysis tool was approximately \$23 per metric ton of CO_2 and increased at a rate of 1.87% per year. The exact value of the social cost of CO_2 used in the analysis varied slightly depending on the base year of the project (due to cost escalation and inflation). Therefore, one can see that the social cost of carbon dioxide had a statistically significant influence on the SIR of each of the 16 projects with the exception of project FSPM091286. Additionally, even if the social cost of CO_2 was different than the value found by the Interagency Working Group on Social Cost of Carbon, which was used in this research, it would still have a statistically significant influence on the SIR of the majority of energy-efficiency projects. While the threshold value for the social cost of CO_2 is fairly low for most projects, the threshold value for the social cost of NO_x is much higher and often exceeds the value used in this research.

The threshold value for statistical significance of the social cost of NO_x ranges from about \$457 to about \$61,700. The value of \$61,700 appears to be an outlier within this data set and occurs on project FSPM091286, the same project that provided the high threshold for the social cost of CO_2. The next highest value, which was about \$14,000, is more in line with the remainder of the values but is still on the high end. The actual value

of the social cost of NO_x used in this research was $1049. The data in Table 4 demonstrate that the value of the social cost of NO_x used in this analysis did not exceed the threshold for statistical significance of many of the projects analyzed. Therefore, the social cost of NO_x at the value used in this research has a statistically significant impact on the SIR of some energy-efficiency projects but not others when taken in isolation; however, it likely increases the SIR of most projects, especially when the social benefits of other air pollutant emissions are also included. Like the threshold values for the social cost of NO_x, the threshold values for the social cost of SO_2 also appear to have a fairly wide range.

The threshold value for statistical significance of the social cost of SO_2 ranges from $110 to $58,434. Again, the high value appears to be an outlier in this data set. The next highest value, which was $8,909, also appears to be much higher than the majority of the values, which range between $100 and $1500. The actual value of the social cost of SO_2 used in this research was $1635.98, which is slightly higher than the majority of the threshold values but is lower than a few of them. Again, we can conclude that the social cost of SO_2 at the level used in this research will have a statistically significant impact on some energy-efficiency projects but not others. The data suggests a general trend of projects with higher energy usage reductions having lower threshold values for SO_2.

The threshold for statistical significance of social costs is influenced by a large number of factors, including the total investment of the project, the magnitude of energy usage reductions, the cost of energy, the energy types saved, and the state in which the project is located. Because the t-Test is a measure of relative variability, projects with high absolute values of total investment will have higher variability (because the

triangular distribution of the total investment is defined based on percentage deviation, rather than absolute deviation), thereby increasing the threshold for statistical significance. Additionally, the magnitude of energy usage reductions and the energy type saved influence the magnitude of pollutant emissions reductions, which in turn influence the required threshold for the social cost of pollutants. The state in which the project is located also affects the air pollutant emissions associated with electricity production. When emissions reductions are low, the social cost must be higher in order to increase the operational cost savings enough compared to the initial investment to have a statistically significant influence.

The threshold values for the social cost of CO_2 tend to be the lowest for each project, followed by the threshold value of the social cost of SO_2 and then the threshold value of the social cost of NO_x. This is likely due to the relative magnitudes of the emissions factors for each energy type, which can be found in Table 2 in the Methodology chapter. The emissions factors for CO_2 are highest for each energy type, followed by the emissions factors for SO_2 and then those for NO_x. Because the emissions of CO_2 are the highest for each energy type, the social cost can be much lower yet still have a statistically significant impact. Likewise, because the NO_x emissions per unit energy are much lower for every energy type, the social cost must be higher in order to have a statistically significant impact. In order to further investigate the influence of the social costs, as well as a number of other input parameters, on the SIR of various projects, a sensitivity analysis was performed on the deterministic results of several project analyses.

Sensitivity Analysis Results

A sensitivity analysis was completed on two projects from the FY12 ECIP program to investigate the effects of variation in input parameters on the cost effectiveness of ECIP projects. All sensitivity analyses are based on percentage deviations of the deterministic values of input parameters. These analyses provide the user with information about which input parameters have the greatest impact on the final SIR of the project and therefore which values must be estimated with the most accuracy. Project TYFR121135 at Ramstein Air Base (AB), Germany, and project CZQZ118002 at Cannon Air Force Base (AFB), New Mexico, were selected for sensitivity analysis due to the fact that both projects involve savings of three energy types, while all other projects involve the savings of only one or two energy types. The specific parameters varied in the sensitivity analysis of these two projects were total investment, energy savings, non-energy costs/benefits, and social cost of pollutants. Additionally, a sensitivity analysis was accomplished for all 16 projects based on energy type. The next sections detail the results of these sensitivity analyses.

Ramstein AB – Project TYFR121135

A detailed sensitivity analysis of project TYFR121135 at Ramstein AB was completed and the results are displayed in the form of spider plots in Figure 2 and Figure 3. Figure 2 displays the results of the sensitivity analysis of the SIR including social benefits, while Figure 3 displays the results of the sensitivity analysis of the SIR excluding social benefits associated with air pollutant emissions reductions. Both figures demonstrate the inverse relationship between total investment and SIR – as the total investment increases,

the SIR decreases. Conversely, energy savings has a direct relationship with SIR – as the annual energy savings increases, the SIR increases. Variations in the initial investment or annual energy savings of +/-20% can have a fairly large influence on the SIR. Each of these variables can create a change in the SIR of about 3.0 based on a variation of +/-20%. Therefore, the SIR is fairly sensitive to each of these values, indicating that the accuracy of the estimate of these parameters is fairly important to the accurate estimation of the SIR. The SIR is relatively insensitive to changes in the social cost of air pollutants within the range of +/-20% of the values used in this research. Therefore, changes of this magnitude in individual social costs have fairly little influence on the final SIR with the largest effect being only about 0.5. The exclusion of all social costs lowers the SIR by only about 0.75, demonstrating that a fairly small variation in either energy usage savings or total investment can have more of an influence on the SIR than completely excluding the social costs from the analysis. In order to investigate whether these trends hold over another project, a detailed sensitivity analysis was also performed on project CZQZ118002 at Cannon AFB, New Mexico.

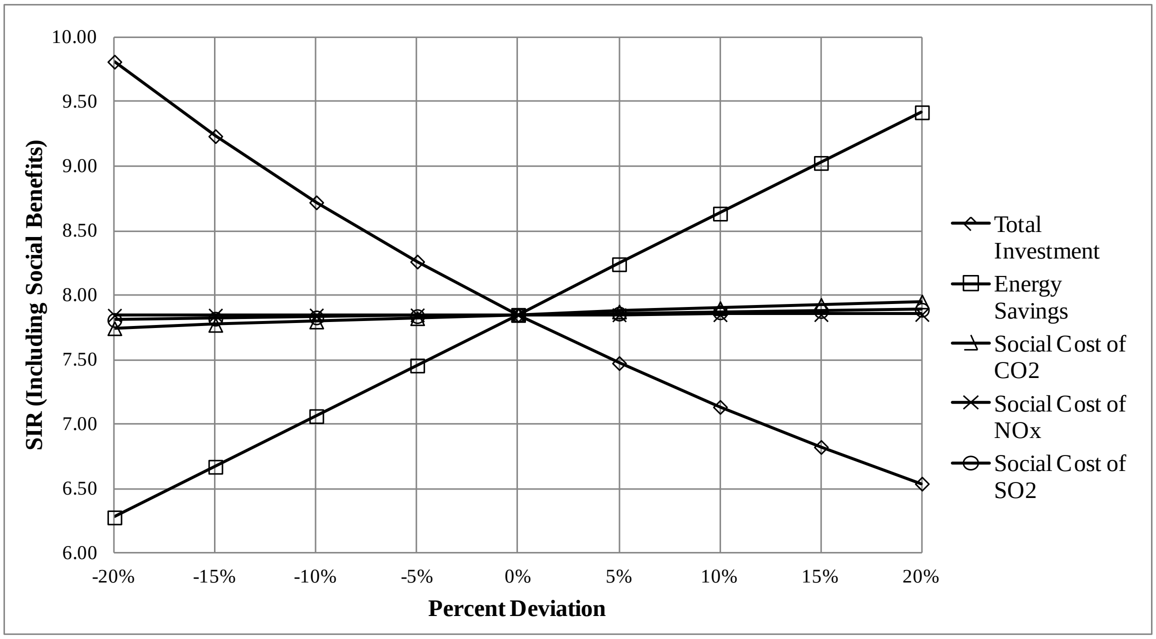


Figure 2. Sensitivity Analysis of Project TYFR121135 (Including Social Benefits)

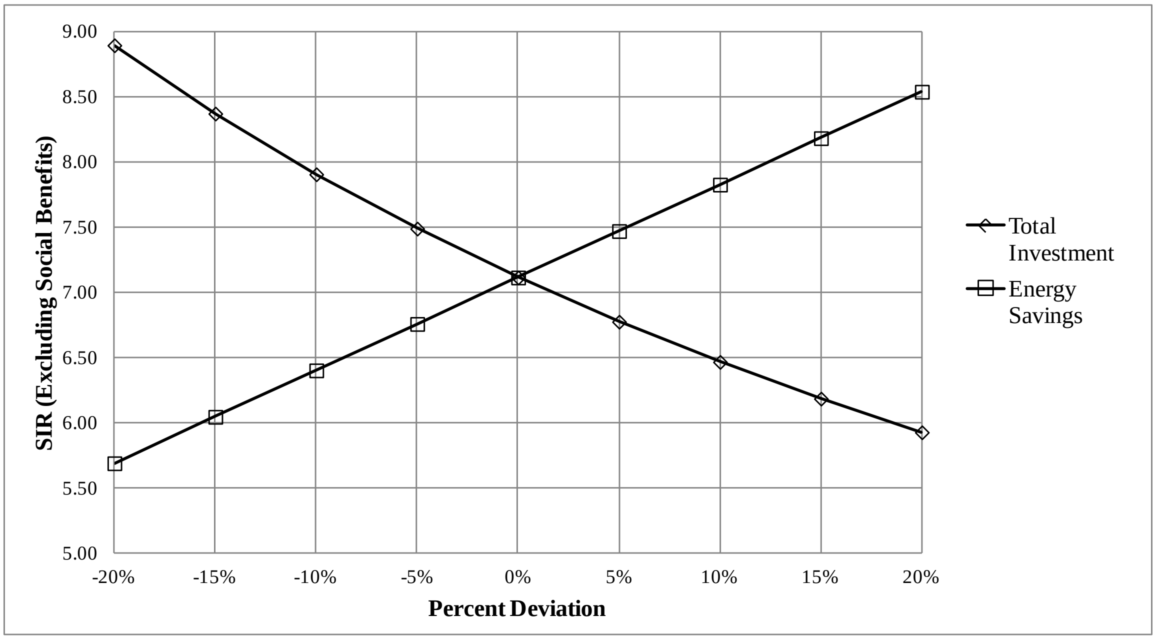


Figure 3. Sensitivity Analysis of Project TYFR121135 (Excluding Social Benefits)

Cannon AFB – Project CZQZ118002

The results of the sensitivity analysis of project CZQZ118002 at Cannon AFB, New Mexico, can be found in Figure 4 and Figure 5. As seen with the sensitivity analysis of project TYFR121135, the SIR is most sensitive to variations in the total investment and annual energy savings. The SIR is relatively insensitive to changes in the social costs of NO_x and SO_2, as well as to changes in non-energy savings/costs. The SIR of this project is noticeably more sensitive to variations in the social cost of CO_2 than it was with project TYFR121135; however, the SIR varies by only 0.75 with a variation of +/-20% in the social cost of CO_2 compared to a change of approximately 3.0 with a variation of +/-20% in the total investment or in annual energy savings. Exclusion of all social costs decreases the SIR from 6.69 to 4.51, a decrease of 2.18. This is a larger absolute effect of the social costs than was found in project TYFR121135, likely due to differing energy types and therefore differing emissions. Additionally, when the social costs are excluded, the sensitivity of the SIR to total investment and energy savings decreases. With social benefits excluded, the SIR changes by only about 2.0 at the extreme values of total investment and energy savings. The sensitivity of the SIR to several different input parameters is influenced by the types of energy that are saved, although these influences are not necessarily apparent. The next section outlines the results of a sensitivity analysis of all 16 projects to energy type, showing the important effect that the energy type has on the SIR.

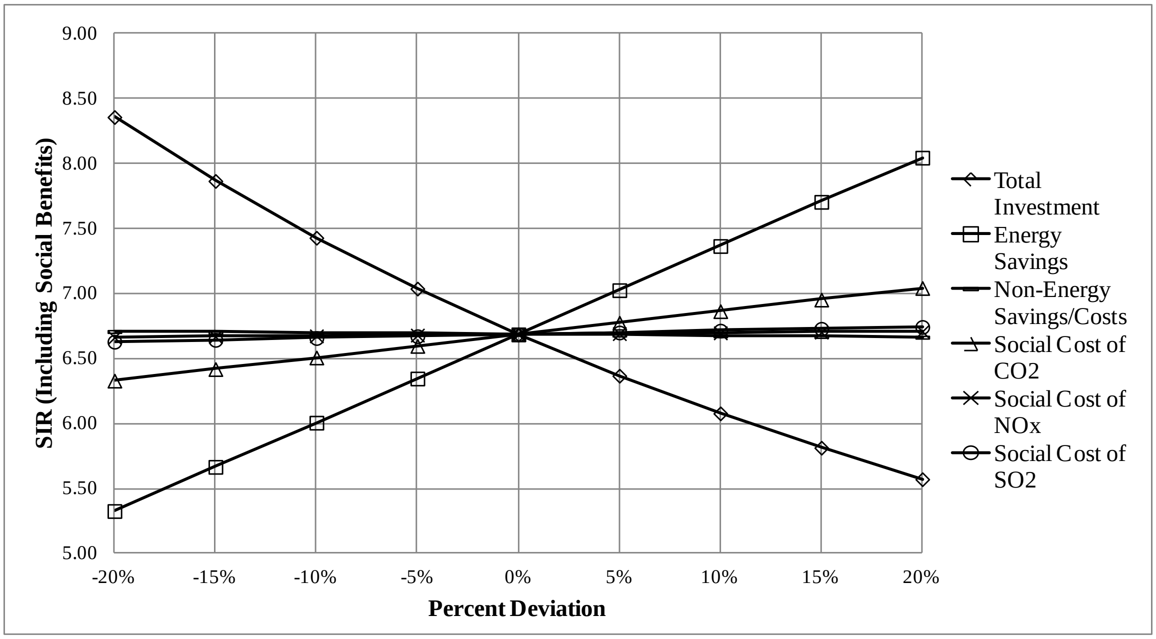


Figure 4. Sensitivity Analysis of Project CZQZ118002 (Including Social Benefits)

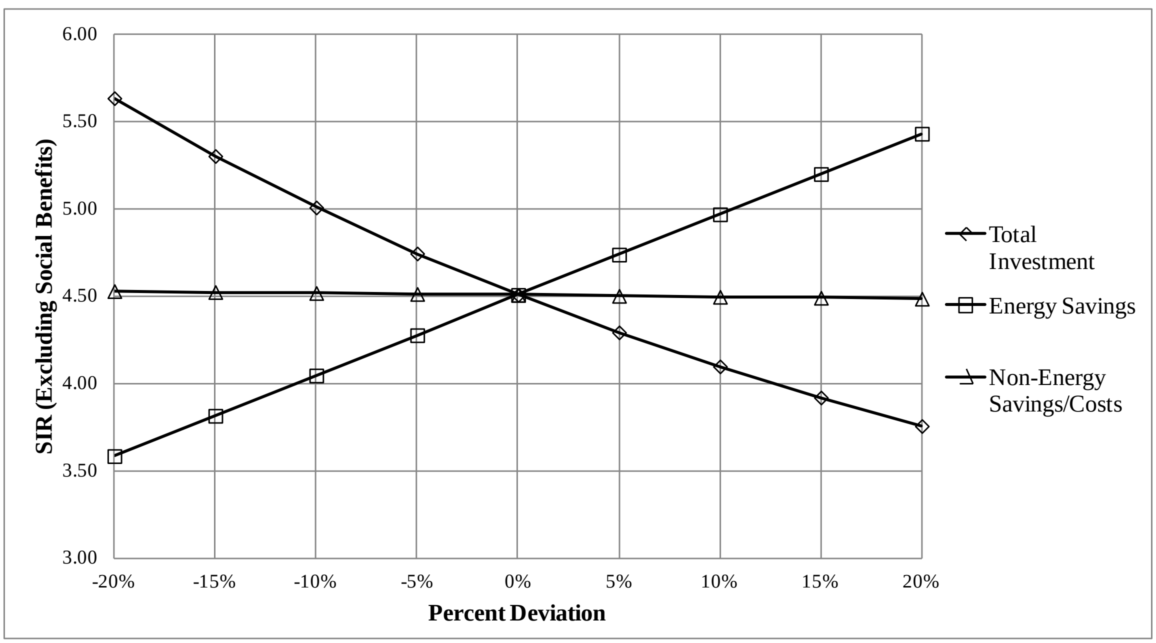


Figure 5. Sensitivity Analysis of Project CZQZ118002 (Excluding Social Benefits)

Sensitivity of SIR to Energy Type

A sensitivity analysis was completed for all 16 projects based on variation in the mix of energy types saved by the projects. For each project, the SIR was calculated based on the assumption that 100% of the energy savings was accounted for by a particular energy type. This was repeated for each energy type saved in the project and for all 16 projects. All other parameters besides energy type were held constant. Table 5 provides the deterministic values of the SIR, both including and excluding social benefits of air pollutant emissions reductions, for the different energy mixes. The data in Table 5 demonstrate that the SIR is highest when electricity is the primary energy type saved, both when social benefits are included and excluded. This is likely because the cost per MBtu of electricity is generally much higher than for natural gas. The only project where the SIR for another energy type exceeds the SIR for electricity is project CZQZ118002, which uses liquefied petroleum gas. This is likely due to the fact that the unit price of liquefied petroleum gas is slightly higher than the unit cost of electricity used in this analysis. Therefore, saving a given amount of energy in the form of liquefied petroleum gas provides a higher return than saving the same amount of energy in the form of electricity.

It is interesting to note that when social benefits of pollutant emissions reductions are incorporated into the calculation of the SIR, the SIR of electricity is higher than that of liquefied petroleum gas for this project. This is likely due to the higher emissions per unit of electricity, resulting in greater cost savings due to the reduction in social costs associated with pollutant emissions. The SIR associated with an energy mix of 100%

Table 5. Results of Sensitivity of SIR to Fuel Type

Project Number	Total Investment	Energy Savings (MBtu)	SIR (Excluding Social Benefits)				SIR (Including Social Benefits)			
			100% Elec	100% NG	100% DFO	100% LPG	100% Elec	100% NG	100% DFO	100% LPG
UHHZ110225	$112,000	38760	-	6.48	-	-	-	9.73	-	-
SGBP120038	$375,067	47724	-	15.07	-	-	-	18.37	-	-
MHMV110059	$661,800	38925	19.57	4.80	-	-	26.45	6.72	-	-
QSEU122014	$125,400	11135	12.88	4.26	-	-	18.51	5.83	-	-
MUHJ114017	$640,961	36887	11.10	7.01	-	-	15.80	8.71	-	-
TYFR121135	$428,740	12282	9.21	6.95	4.78	-	10.73	7.47	5.48	-
QSEU122012	$1,804,000	69786	11.31	3.80	-	-	15.85	5.06	-	-
NZAS110301	$128,000	2926	6.16	-	-	-	8.16	-	-	-
CZQZ118002	$526,247	16371	6.91	3.03	-	9.39	10.87	4.12	-	10.72
GHLN117005	$266,800	11209	-	5.91	-	-	-	7.59	-	-
HEKP124000	$113,000	199	1.02	-	-	-	1.09	-	-	-
ASHE121005	$118,000	120	1.29	-	-	-	1.39	-	-	-
TYFR101089	$580,000	474	1.30	-	-	-	1.46	-	-	-
FSPM102214	$3,500,000	1335	1.97	0.88	-	-	2.05	0.95	-	-
FSPM091286	$121,118	45	1.78	-	-	-	1.79	-	-	-
MHMV100072	$149,200	22	2.52	-	-	-	2.63	-	-	-

natural gas is generally much lower than that associated with 100% electricity, likely due to the lower per-MBtu cost of natural gas. Based on these results, it can be concluded that if a specific amount of energy is to be saved, the SIR can be maximized by maximizing the amount of electricity to be saved, rather than attempting to save other types of energy. The SIR is also greatly influenced by the uncertainty in input parameters. In order to investigate the influence of uncertainty on the SIR, probabilistic results of a life-cycle full-cost analysis were compared with the deterministic results provided by the BLCC program.

Comparison of Deterministic and Probabilistic SIR

This section outlines the results of comparing the probabilistic and deterministic values of the SIR, both including and excluding the social benefits of reduced emissions. The purpose of this section is to examine the impact of uncertainty in input parameters on the calculated SIR for a project. All simulations were accomplished by varying input parameters according to the assumptions found in the Methodology chapter. The SIR (excluding social benefits) calculated deterministically provides the basis for comparison as this is the default SIR value currently used for ranking projects. Table 6 provides a summary of the probabilistic results of a simulation that excluded the social benefits of reduced pollutant emissions. Table 7 provides a summary of the probabilistic results of a simulation that included the social benefits. The minimum, mean, and maximum values of the probabilistic SIR found in Table 6 and Table 7 are the minimum, mean, and maximum values generated by the 1000-iteration Monte Carlo simulation.

Table 6. Comparison of Probabilistic and Deterministic Results

Project Number	Deterministic SIR (Excluding Social Benefits)	Probabilistic SIR (Excluding Social Benefits)			Probability of SIR Exceeding Deterministic Value	Probability of SIR Exceeding 1.25
		Minimum	Mean	Maximum		
UHHZ110225	6.48	3.92	5.86	8.11	21.8%	100.0%
SGBP120038	15.07	9.13	13.63	18.88	21.9%	100.0%
MHMV110059	12.70	8.17	11.53	15.74	23.3%	100.0%
QSEU122014	4.86	3.02	4.40	6.06	21.2%	100.0%
MUHJ114017	8.21	5.21	7.44	10.22	22.2%	100.0%
TYFR121135	7.10	4.50	6.45	8.82	21.5%	100.0%
QSEU122012	3.85	2.34	3.48	4.82	21.9%	100.0%
NZAS110301	6.16	3.87	5.59	7.74	24.3%	100.0%
CZQZ118002	4.51	2.88	4.09	5.59	21.5%	100.0%
GHLN117005	5.91	3.58	5.35	7.41	22.1%	100.0%
HEKP124000	1.02	0.65	0.92	1.26	23.4%	0.3%
ASHE121005	1.29	0.84	1.17	1.58	23.0%	30.3%
TYFR101089	1.30	0.88	1.26	1.75	24.4%	51.7%
FSPM102214	1.79	1.19	1.62	2.15	22.1%	98.0%
FSPM091286	1.78	1.21	1.61	2.08	21.0%	98.3%
MHMV100072	2.52	1.72	2.29	2.96	22.0%	100.0%

Table 7. Comparison of Probabilistic and Deterministic Results

Project Number	Deterministic SIR (Excluding Social Benefits)	Probabilistic SIR (Including Social Benefits)			Probability of SIR Exceeding Deterministic Value	Probability of SIR Exceeding 1.25
		Minimum	Mean	Maximum		
UHHZ110225	6.48	5.20	8.59	12.29	97.3%	100.0%
SGBP120038	15.07	10.40	16.40	23.10	70.8%	100.0%
MHMV110059	12.70	9.86	15.30	21.45	88.5%	100.0%
QSEU122014	4.86	3.76	5.96	8.42	91.6%	100.0%
MUHJ114017	8.21	6.23	9.60	13.49	85.5%	100.0%
TYFR121135	7.10	4.79	7.06	9.73	47.6%	100.0%
QSEU122012	3.85	3.13	4.56	6.43	87.0%	100.0%
NZAS110301	6.16	4.66	7.24	10.21	84.6%	100.0%
CZQZ118002	4.51	3.71	5.89	8.36	96.2%	100.0%
GHLN117005	5.91	4.22	6.75	9.56	82.5%	100.0%
HEKP124000	1.02	0.68	0.98	1.33	38.9%	1.7%
ASHE121005	1.29	0.88	1.26	1.69	41.9%	51.0%
TYFR101089	1.30	0.91	1.32	1.81	34.8%	64.1%
FSPM102214	1.79	1.21	1.68	2.24	32.4%	99.6%
FSPM091286	1.78	1.22	1.62	2.09	23.0%	99.3%
MHMV100072	2.52	1.78	2.38	3.08	33.4%	100.0%

Table 6 demonstrates that the mean probabilistic value of the SIR excluding social benefits did not exceed the deterministic value of SIR excluding social benefits for any of the 16 projects. In fact, the probability distribution indicates that there is only a probability of approximately 21-23% that the actual value of the SIR will meet or exceed the deterministic value currently used to rank projects. When social benefits are included in the calculation of the SIR, there is generally a much higher probability that the actual SIR will meet or exceed the deterministic SIR used to rank projects. When the deterministic value of the SIR is close to the threshold for funding (1.25), there is a reasonable probability that the actual value of the SIR will not exceed the threshold. For example, project ASHE121005 has a calculated deterministic SIR of 1.29, which exceeds the threshold for funding; however, when a probability distribution of the SIR is generated, there is only a 30.3% chance that the actual SIR will exceed the funding threshold when social benefits are excluded. When social benefits are included in the calculation, the probability of the SIR exceeding 1.25 increases to 51.0%. The inclusion of the social benefits of reduced air pollutant emissions generally increases the mean probabilistic SIR, although the magnitude of increase varies between projects.

Projects with lower energy usage savings generally have a smaller increase in the mean probabilistic SIR when social benefits are incorporated. Additionally, the mean probabilistic SIR including social benefits tends to be greater than the deterministic SIR excluding social benefits for projects with higher energy usage savings but not necessarily for projects with lower energy usage savings. The minimum probabilistic SIR (the minimum value generated by the Monte Carlo simulation) including social costs is still lower than the deterministic SIR excluding social benefits for all 16 projects,

indicating that there is still a probability that even with social benefits, the actual SIR could still be less than the deterministic SIR value currently used to rank projects. The probability of the actual SIR exceeding the deterministic SIR excluding social benefits generally increases for most projects when the social benefits are included; however, the magnitude of the change is highly variable among projects. As expected, the probability of exceeding the threshold value virtually always increases when social benefits of reduced air pollutant emissions are incorporated into the SIR calculation.

The probabilistic life-cycle full-cost analysis tool provides the minimum, mean, and maximum probabilistic values of the SIR from the distribution generated by the Monte Carlo simulation, both including and excluding the social benefits of reduced air pollutant emissions. Additionally, the probabilistic life-cycle full-cost analysis tool provides graphs of the SIR distribution. Figure 6 and Figure 7 display the probabilistic results of the SIR for project TYFR121135 at Ramstein AB, Germany, both including and excluding the social benefits of reduced air pollutant emissions. The histogram in each graph represents the probability distribution of the SIR, while the curve shows the cumulative probability of the SIR. Using this curve, the probability of the actual SIR exceeding a specific value can be determined, both when social benefits are included and excluded. The cumulative probability curve will always proceed down from the top left to the bottom right of the graph. This is different from the usual convention for cumulative probability functions. It was presented this way in this research in order to highlight the probability of the actual SIR *exceeding* the value of interest. The use of the cumulative probability curve and the histogram of SIR values help to better characterize the

uncertainty in the SIR values calculated for a specific project, allowing the decision-maker to better understand the uncertainty associated with their estimates.

There is a great deal of variability and uncertainty inherent in many of the input parameters required to calculate an accurate SIR. As was shown above, there is only about a 22% probability of the actual SIR meeting or exceeding the deterministic value currently used to rank projects. Therefore, the deterministic SIR does not characterize the uncertainty inherent in the estimate of the SIR. It may not be a strong indicator of actual project economic performance. Probabilistically modeling the SIR provides more insight as to the potential values that the actual SIR could take, thereby providing the decision maker with more information to assist in making more informed investment decisions.

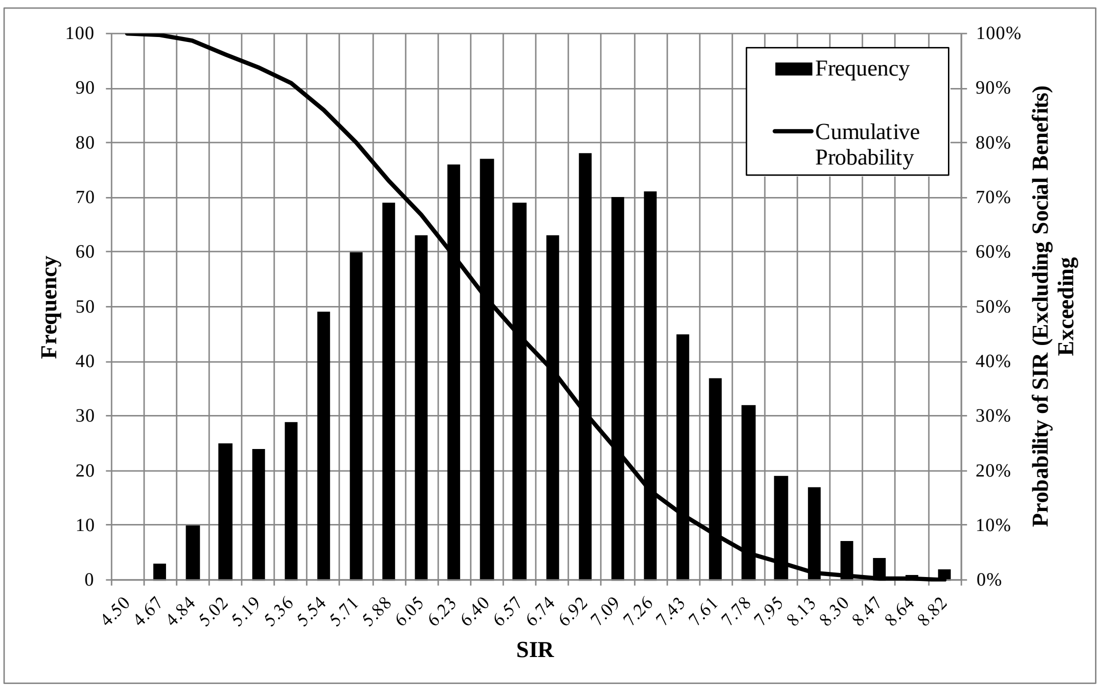


Figure 6. Probability Distribution of SIR (Excluding Social Benefits) for Project TYFR121135

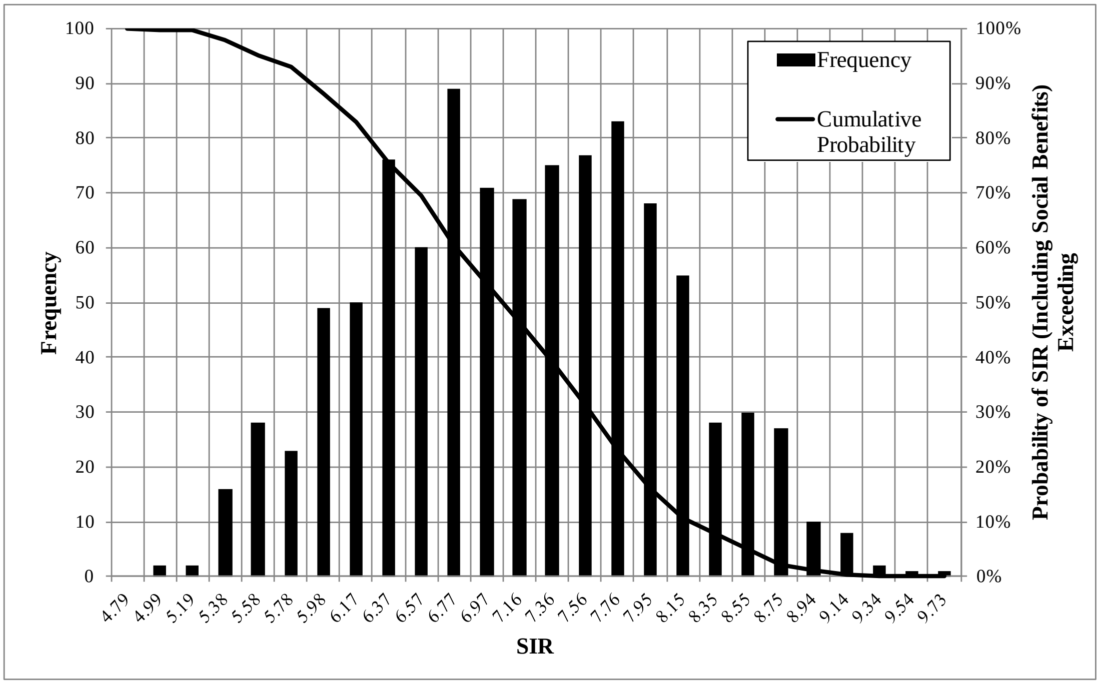


Figure 7. Probability Distribution of SIR (Including Social Benefits) for Project TYFR121135

Investigation of ECIP Project Ranking

After ECIP projects are determined to be cost effective, judged by having an SIR greater than 1.25, they are generally ranked against other ECIP projects for limited funding. The current method used by AFCESA to rank ECIP projects is to multiply the SIR by the BIR to determine a score for each project. Projects are then ranked based on their scores and are funded, at least in theory, in rank order (other factors, such as the amount of money available in different programs and in each Air Force Major Command, may affect which projects actually get funded). This section investigates the effects of different ranking schemes on the final rank order of the top ten ECIP projects for the

FY12 ECIP program. The tables in this section provide only the ranking based on the different parameters; the actual parameter values used to generate the rankings can be found in Appendix G.

AFCESA Ranking

This section outlines the parameters used by AFCESA to rank the top ten ECIP projects from the FY12 program. Table 8 shows the ranking of the projects according to the SIR and BIR values used by AFCESA to determine a score for each project. The SIR values used by AFCESA for their rankings were generally the values found in the ECIP report for each project rounded to one decimal place, with one exception. The spreadsheet provided by AFCESA shows the SIR for project GHLN117005 at FE Warren AFB to be 2.40, while the ECIP report from the BLCC program for the same project shows the SIR to be 5.91. Additionally, the BIR provided by AFCESA for some projects differs from the values that could be calculated by dividing the annual energy savings (in MBtu) by the total investment from the ECIP report. For some projects, AFCESA appeared to have used the Programmed Amount that was provided in their summary spreadsheet, which was not always the same as the total investment found in the ECIP report, to calculate the BIR. For consistency in this research, the AFCESA ranking was not used as a baseline for comparison of projects due to the aforementioned inconsistencies in the calculation of ranking parameters. Instead, a ranking was determined based on the product of the deterministic SIR from the ECIP report and the BIR based on the annual energy usage reduction and total investment, both from the

ECIP report. The next section outlines how this ranking differs from the AFCESA ranking and investigates how the use of SIR and BIR values derived from different assumptions influences the ranking of projects.

Table 8. Project Parameter Values Provided by AFCESA

Project Number	SIR	BIR	SIR*BIR	AFCESA RANKING
UHHZ110225	6.50	0.34607	2.24946	1
SGBP120038	15.00	0.12693	1.90388	2
MHMV110059	12.70	0.05880	0.74675	3
QSEU122014	4.90	0.09768	0.47861	4
MUHJ114017	8.20	0.05755	0.47188	5
TYFR121135	7.10	0.03157	0.22417	6
QSEU122012	3.90	0.04255	0.16595	7
NZAS110301	6.20	0.02286	0.14173	8
CZQZ118002	4.50	0.02380	0.10708	9
GHLN117005	2.40	0.04198	0.10076	10

Ranking Based on SIR and BIR

A comparison of deterministic rankings under different assumptions is provided in Table 9. The second column shows the AFCESA ranking based on the parameters found in Table 8. The third column shows the ranking based on the SIR values found in the ECIP report (which exclude social benefits) and the BIR calculated by dividing the annual energy savings by the total investment, both found in the ECIP report. The fourth column shows the ranking based on the product of the deterministic SIR including social benefits and the BIR as calculated above. The ranking in the third column differs slightly from the ranking provided by AFCESA. The most notable difference is the ranking of project GHLN117005, which moves from position ten in the AFCESA ranking to

position six. This is likely due primarily to the value of the SIR used by AFCESA (2.40), which differs significantly from the value found in the ECIP report (5.91). Additionally, the projects in positions four and five in the AFCESA ranking switched order in the ranking in the third column, likely due to the different calculation of the BIR. For the sake of consistency, the ranking found in the third column will be considered the basis of comparison for the remainder of the rankings calculated in this research. The ranking based on the inclusion of the social benefits of reduced air pollutant emissions, found in the fourth column, was then compared to this baseline.

Table 9. Comparison of ECIP Project Rankings

Project Number	AFCESA Ranking	Deterministic SIR*BIR		Deterministic SIR		Deterministic SIR*CIR		Mean Probabilistic SIR*CIR	
		E	I	E	I	E	I	E	I
UHHZ110225	1	1	1	5	4	1	1	2	1
SGBP120038	2	2	2	1	1	3	3	3	3
MHMV110059	3	3	3	2	2	2	2	1	2
QSEU122014	4	5	5	8	8	6	6	6	6
MUHJ114017	5	4	4	3	3	4	4	4	4
TYFR121135	6	7	7	4	6	8	8	7	8
QSEU122012	7	8	9	10	10	10	10	10	10
NZAS110301	8	9	10	6	5	5	5	5	5
CZQZ118002	9	10	8	9	9	7	7	8	7
GHLN117005	10	6	6	7	7	9	9	9	9

Based on the results found in the fourth column of Table 9, the inclusion of the social benefits of reduced air pollutant emissions can slightly change the ranking of energy efficiency projects. While the change is not significant in the ranking of only ten projects, the effect would likely be larger in magnitude for a listing of several hundred projects. If the inclusion of social benefits only had the effect of increasing the SIR of all projects equally, it would provide little benefit to the prioritization of ECIP projects;

however, due to a limited budget to fund projects, sometimes projects deemed cost effective are left without funding. The fact that the inclusion of the social benefits of air pollutant emissions reductions changes the ranking does have an important effect on project prioritization for funding. The rankings based on the mean and 95^{th} percentile probabilistic values of the SIR and BIR were also investigated; however, these results are not shown here as they produced the same rank order as the deterministic values. While the standard practice by AFCESA currently is to rank projects based on a score derived from the product of the SIR and BIR, the next section will examine the effect on the ranking of projects if only the SIR is used to produce the ranking.

Ranking Based on SIR

The ranking of projects based on SIR and BIR includes both a measure of economic effectiveness (SIR) and a measure of the amount of energy savings achieved by the project, which helps to meet the intent of the ECIP program. If project ranking were based only on SIR, the ranking would be based solely on an economic measure of project effectiveness. Therefore, it is instructive to investigate how the ranking would differ if only the SIR were used for ranking purposes. The fifth and sixth columns of Table 9 compare rankings based on SIR only, both including and excluding social benefits associated with energy use reductions, against the baseline ranking derived from the SIR and BIR. A probabilistic analysis, based on both mean and 95^{th} percentile values, was also accomplished, but the results are not shown because they produced the same ranking as the deterministic values. As is evidenced by the results shown in Table 9, the ranking changes fairly significantly when only the SIR is used for ranking. Additionally, the

ranking changes further when social benefits are incorporated into the calculation of the SIR. The change in ranking is likely due to the different characteristics of the SIR and BIR.

The SIR is strictly a measure of economic effectiveness, although it implicitly incorporates the annual energy savings of a project through the calculation of the operational cost savings. The SIR considers the financial impact of saving different energy types through the use of the unit cost of each energy type. Therefore, savings of different energy types are not compared equally due to their differing unit costs and differing pollutant emissions. The BIR serves to compare the energy savings of different projects without regard for differing unit costs. The exclusion of the BIR from the ranking of projects therefore serves to give preference to projects with higher unit costs of energy, even if their absolute energy savings is comparable to another project. This may make more financial sense, but it may not make sense if the objective of the ECIP program is to reduce energy consumption for non-financial reasons. One objective advanced by the federal government for reducing energy consumption is the reduction in emissions of greenhouse gases, particularly carbon dioxide. Therefore, a new measure was developed as part of this research to give greater weight to reductions of greenhouse gases. The next section will outline the results of rankings based on the SIR and the CO_2-to-Investment Ratio (CIR).

Ranking Based on SIR and CIR

While the inclusion of the BIR in project rankings provides greater weight to the absolute energy savings of a project, the CIR provides a more direct measure of greenhouse gas emissions reductions associated with energy use reductions. The seventh and eighth columns of Table 9 compare the project ranking based on the product of the deterministic SIR (both including and excluding social benefits) and the deterministic CIR against the baseline ranking. As is evidenced by Table 9, the use of the CIR rather than the BIR in ranking projects changes the ranking; however, the inclusion of the social benefits of air pollutant emissions reductions does not further change the ranking. This is presumably because a majority of the social benefits are realized through the reduction of carbon dioxide emissions, which tend to account for most of the emissions reductions associated with reduced energy consumption. Therefore, projects with high CO_2 emissions reductions are already weighted more heavily when the CIR is used in the ranking, so the additional inclusion of the social benefits of pollutant emissions reductions does not further change the ranking. The ninth and tenth columns of Table 9 compares the ranking based on the product of the mean probabilistic SIR (including and excluding social benefits) and the mean probabilistic CIR for each project against the baseline ranking. As is shown in Table 9, the use of the probabilistic CIR and SIR (excluding social benefits) does change the ranking versus the deterministic values of these parameters. The further inclusion of the social benefits in the calculation of the probabilistic SIR changes the ranking, unlike the inclusion of the social benefits in the deterministic calculation of the SIR and CIR. Additionally, both of these rankings are

different from the rankings based on the SIR and BIR as well as the SIR alone. This section has demonstrated that the selection of parameters to be used in the ranking of ECIP projects has an influence on the resulting ranking of projects.

The selection of different parameters to be used for ranking of energy efficiency projects can be justified depending on the objectives of the ranking. The SIR provides a purely economic measure of project performance. The inclusion of the social benefits of air pollutant emissions reductions in the SIR provides more consideration of the absolute energy reductions, as well as the emissions saved from each different type of energy. The BIR provides a measure of the absolute energy savings of a project without regard for the unit costs or emissions of the energy being saved. The CIR provides a measure of the reductions in greenhouse gas pollution associated with the energy use reductions of a project. The inclusion of each of these different factors in the ranking of projects has a different influence on the ranking and therefore which projects would likely receive funding in a given year. Consequently, the objectives of the decision-maker are very important when determining how projects are ranked and ultimately funded.

V. Conclusions

This research effort sought to investigate the incorporation of social externalities of energy consumption into life-cycle cost analyses of energy efficiency projects. Additionally, it sought to develop a probabilistic life-cycle full-cost analysis tool to incorporate both social externalities and uncertainty into life-cycle cost analyses of Energy Conservation Investment Program (ECIP) projects. The literature review included discussion of sustainable development, the ways in which discounting addresses intergenerational equity and the time-value of money, and how the social costs of air pollutants have been estimated in prior studies. The methodology chapter outlined the development of the probabilistic life-cycle full-cost analysis tool and detailed the analysis of ECIP projects that was accomplished with the tool. The results chapter detailed the findings of the ECIP project analyses. This chapter will discuss the results of the analysis of ECIP projects, detail some of the limitations of this research, and outline some potential areas for future research.

Discussion of Results

The primary result of this research effort was the development of a probabilistic life-cycle full-cost analysis tool and user guide, which can be used by decision-makers to better understand both the uncertainty in their investment decisions as well as the impact of social externalities. The ECIP project analysis offered some insight into the influence of the consideration of these factors in the performance of economic analyses on ECIP projects and the prioritization of these projects for funding.

The statistical analysis of the savings-to-investment ratio (SIR) indicated that the threshold values of the social costs of carbon dioxide (CO_2), oxides of nitrogen (NO_x), and sulfur dioxide (SO_2) varied widely between projects. The social cost of carbon dioxide used as the default value in the probabilistic life-cycle full-cost analysis tool exceeded the threshold for statistical significance for all but one project analyzed in this research. This particular project was primarily a water conservation project and had very low annual energy usage reductions, thereby requiring larger social costs to have statistical significance. The social cost of NO_x used in this research fell within the range of threshold values, indicating that inclusion of the social benefits of NO_x emissions reductions will have a statistically significant impact only on some energy efficiency projects. The same was true for the social cost of SO_2, although the value used in this research exceeded the threshold for statistical significance in the majority of projects. When the social benefits of the reduction of all three pollutants are combined, there is a very high probability that the SIR will have a statistically significant increase; however, the magnitude of increase will vary across different projects and depends on a number of factors. This research investigated the influence of these factors on the SIR through the use of a sensitivity analysis.

The sensitivity analysis of the influence of various input parameters on the SIR indicated that total investment and energy usage savings had the largest influence on the SIR of a project. The accurate estimation of these two values, therefore, should be a high priority for anyone performing a life-cycle cost analysis of energy efficiency projects. The SIR was relatively insensitive to changes in non-energy savings or costs; however, the magnitude of these non-energy savings or costs relative to other costs and benefits

would dictate the sensitivity of the SIR to these values. The SIR was found to be relatively insensitive to changes of +/-20% in any individual social cost value. The social cost of carbon dioxide, however, has been estimated by various studies to differ by orders of magnitude. The value of the SIR would likely be quite sensitive to variations of this magnitude in the social costs. For an economic analysis of an individual energy efficiency project, the order of magnitude of social costs is likely very important. It is likely less important that the value be estimated precisely due to the insensitivity of the SIR to small variations in the social cost. The SIR does, however, display a high degree of sensitivity to the energy type saved in the project due to differing unit costs and differing emissions of each energy type.

The results of this research indicate that the SIR is fairly sensitive to the type of energy saved by the project, sometimes experiencing a doubling or more of the SIR when a different energy type is considered in the analysis. The highest SIR for each project analyzed in this research was generally associated with an energy mix of 100% electricity due to the higher price per unit of energy of electricity. The implication of this result is that decision-makers can realize the highest SIR by focusing their attention on projects that reduce electricity consumption, rather than other types of energy. In addition to higher unit costs of energy, the emissions per unit of energy were also higher for electricity than for other energy sources. This increased the SIR further when the social benefits of reduced pollutant emissions were incorporated into the SIR calculation.

The discussion thus far has focused on deterministic results where input parameters are assumed to be point estimates that do not vary. To account for the variability inherent in the input parameters to a life-cycle cost analysis, a Monte Carlo

simulation was used to characterize this uncertainty and compare probabilistic and deterministic results. The results of the comparison of the probabilistic and deterministic SIR indicated that the deterministic SIR may not adequately characterize the uncertainty associated with this value. This research demonstrated a probability of only about 22% that the actual SIR (excluding social benefits of pollutant reductions) would exceed the deterministic value found in the ECIP report from the Building Life-Cycle Cost (BLCC) program. When social benefits were incorporated into the calculation of the SIR, this probability increased for the majority of projects analyzed in this research; however, this increase was not constant across all projects. Due to the variability in the estimate of the SIR and the sensitivity of this value to variations in input parameters, the deterministic value of the SIR may not provide a good measure of the cost effectiveness of an individual project.

A decision-maker would likely have a much better impression of the variability of the SIR estimate by performing a Monte Carlo simulation like the one provided by the probabilistic life-cycle full-cost analysis tool. The use of simulation allows the user to better understand the variability of the SIR and make more informed decisions using the probability distribution of the value, rather than simply a point estimate. While the probability distribution of the SIR is useful when examining an individual project, its use becomes more complicated when projects are compared to each other and ranked.

This research examined the effect of the incorporation of the social benefits of reduced air pollutant emissions, as well as the selection of financial measures and the inclusion of uncertainty, on the ranking of ECIP projects for funding. The parameters of SIR, Btu-to-investment ratio (BIR), and CO_2-to-investment ratio (CIR) were used in

various combinations to examine their effect on the ranking of ECIP projects. The ranking of projects by SIR alone gives preference to projects with the highest unit costs of energy because of the higher annual cost savings resulting from a unit of energy savings. The ranking of projects by a score derived by the product of the SIR and BIR, which is current standard practice by the Air Force Civil Engineer Support Agency, tends to give preference to projects with the highest energy savings, regardless of energy type. The CO_2-to-Investment Ratio measure was developed for this research as a measure of the greenhouse gas emissions reductions associated with a project, which takes into account both the total energy savings and the types of energy saved. The ranking of projects by a score calculated as the product of the SIR and CIR gives preference to projects that save the types of energy with higher carbon dioxide emissions per unit energy. It therefore would bias the analysis in favor of projects with high electricity savings. The reduction in consumption of electricity provides the greatest reduction in carbon dioxide emissions of any energy type analyzed in this research. This is somewhat dependent on the state in which the electricity reductions take place; however, the carbon dioxide emissions of a given unit of electricity are generally higher in all states than for other energy types.

The selection of parameters for ranking has an important influence on the ranking of projects, as was indicated by the change in rankings under each different scenario in this research. The incorporation of the social benefits of air pollutant emissions reductions further influenced the ranking of projects, except in the case of the ranking utilizing the deterministic SIR and CIR. In this case, the ranking did not change between the SIR with social benefits and the SIR without social benefits. Presumably this is

because the CIR already accounts for reduced carbon dioxide emissions, which make up a majority of the social benefits incorporated into the SIR. Therefore, the inclusion of the social benefits in the calculation of the SIR did not have any further influence on the ranking.

This research also investigated how the probabilistic calculation of the parameters of SIR, BIR, and CIR influenced the ranking of the top ten projects of the Fiscal Year 2012 (FY12) ECIP program. Based on the results of this research, it appears that the use of Monte Carlo simulation had a low impact on the project ranking. The rankings derived from the mean probabilistic and 95th percentile probabilistic values of the SIR alone and product of the SIR and BIR, both including and excluding social benefits, were the same as those derived from the deterministic values of these parameters. When the projects were ranked by the product of the SIR and CIR, the ranking changed slightly when probabilistic values were used rather than deterministic values. The fact that the rankings remained largely the same may indicate that the use of the mean and 95th percentile probabilistic values for ranking provides an inadequate mechanism for incorporating uncertainty into project rankings. While Monte Carlo simulation provides a good way to examine the uncertainty associated with the SIR of a single project, the use of the mean probabilistic value does not adequately capture this uncertainty when ranking projects. Therefore, the incorporation of the uncertainty of the ranking parameters may have to be factored into project rankings more qualitatively. It will likely require judgment on the part of the individual ranking the projects as to what the conceivable range of possible SIR values might be, and how they might influence the best ranking.

Limitations

This research effort has several limitations. First, the probabilistic life-cycle full-cost analysis tool relies on a number of uncertain input parameters. Cost estimates used in any economic analysis are always at least somewhat uncertain. Additionally, the future energy savings of a project are difficult to predict and often rely on factors beyond the control of those making investment decisions. The social costs of air pollutants are highly uncertain and somewhat controversial from an economic and philosophical standpoint. The emissions factors used in this research to calculate emissions for each energy type are also fairly uncertain and can have a large effect on the calculated SIR. This research assumed that the values of the social costs of air pollutants were relatively certain, at least within a reasonable range of variation. While the sensitivity analysis indicated that the SIR was not very sensitive to small variations in social costs of pollutants, variations by orders of magnitude would have a large influence on the SIR. The use of Monte Carlo simulation helps decision-makers better understand the uncertainty of input parameters and the resultant uncertainty of model results; however, the simulation itself relies on an accurate characterization of the uncertainty of the parameters in the form of probability distributions. Any users of the probabilistic life-cycle full-cost analysis tool should be aware of its limitations, particularly the estimation of the social benefits of pollutants.

In addition to the limitations of the probabilistic life-cycle cost analysis tool, the project analysis performed with the tool has some limitations. The conclusions of the ECIP project analysis part of this research are based on results from the analysis of a fairly small number of projects. Although the trends recognized in these few projects, such as differences in project ranking due to differing input parameters, will likely

extrapolate to a larger sample, there are likely trends that were missed because of the small number of projects. Additionally, the projects analyzed in this research were not randomly selected from the population of all ECIP projects. The projects analyzed were the top ten ranked projects from the FY12 ECIP program and six projects from the bottom ten projects. The projects in the top ten and bottom ten likely shared similar characteristics that caused them to be ranked near each other. These characteristics may have negatively affected the results found in this research.

Future Research

This research answered some questions about the inclusion of environmental and social externalities in life-cycle cost analyses, but it also prompted a number of others. Future research could focus on improving the means by which environmental and social externalities are incorporated into life-cycle cost analyses of projects and benefit-cost analyses of policy decisions. It is apparent that more research is still required to determine the ideal value of the social cost of air pollutants, specifically greenhouse gases. Additionally, research on the quantification of the full costs of water for use in water efficiency projects could help to better characterize the environmental and social externalities associated with water consumption. Research on the quantification of other benefits of energy and water efficiency projects, as well as the use of sustainable building methods, could help to make the business case for their incorporation into future government projects. Examples of other benefits of sustainable building that could benefit from quantification include increased worker productivity, better employee health, reduced environmental degradation, and reduced peak electricity demand. In order

to better understand the environmental consequences of the materials that go into a project, research could focus on the full life-cycle of the materials used in the construction of a project. This could lead to the inclusion of embodied energy in the consideration of an energy efficiency project. For example, a comparison of the energy saved by a project to install solar photovoltaic panels could focus on the energy expended in the manufacture and installation of the panels for comparison with the energy savings of the completed project.

Conclusion

The path of energy consumption on which the world currently finds itself is unsustainable. Limited energy resources and global climate change will affect the well-being of future generations. The social and environmental effects of energy consumption are externalities imposed on people not involved in the decision to use energy. A number of scholars have suggested that consideration of the full costs, including environmental and social externalities, in economic analyses of investment decisions would help to improve the sustainability of our decisions. Due to the large impact of our built infrastructure, consideration of these externalities in building investment decisions is especially important. The probabilistic life-cycle full-cost analysis tool developed as part of this research will hopefully prove to be a useful tool for incorporating these externalities into the analysis of ECIP projects. This tool does not incorporate all societal benefits of energy usage reductions; however, it does provide a starting point for

incorporating these social benefits and costs into life-cycle cost analyses. The methodology used here could be expanded to include other social benefits and costs for a more complete analysis of the full costs of other government actions.

Appendix A. Probabilistic Life-Cycle Full-Cost Analysis Tool Screenshots

Probabilistic Life-Cycle Full-Cost Analysis Input

Location:	New Mexico
Project Title:	Kirtland Irrigation
Base Date:	November 1, 2010
BOD:	November 1, 2011
File Name:	

Discount Rate (Percent):	3.0%	
Analyst:	ACD	
Preparation Date:	February 10, 2012	
	Years	Months
Economic Life (years):	20	0

Investment	
Construction Cost:	$129,000
SIOH:	$7,600
Design Cost:	$12,600
Total Cost:	$149,200
Salvage Value of Existing Equipment:	$0
Public Utility Company:	$0
Total Investment:	$149,200

Energy and Water Savings (+) or Cost (-)

Base Date Savings, unit costs, & discounted savings

Item	Unit Cost	Usage Savings		Annual Savings	Discount Factor	Discounted Savings
Electricity	$24.91105	140.8	MBtu	$3,507	14.127	$49,550
Natural Gas			MBtu	$0		$0
Distillate Fuel Oil (#1,#2)			MBtu	$0		$0
Liquefied Petroleum Gas			MBtu	$0		$0
Energy Subtotal		140.8	MBtu	$3,507		$49,550
Water	$1,052.00	22.00	Mgal	$23,144	14.114	$326,654
Water Subtotal		22.00	Mgal	$23,144.00		$326,654
Total				$26,651		$376,205

Non-Energy Savings (+) or Cost (-)

Item (Name)	Savings/Cost	Occurrence	Discount Factor	Discounted Savings
Annually Recurring				
				$0
				$0
				$0
Annually Recurring Subtotal	$0			$0
Non-Annually Recurring				
				$0
				$0
				$0
Non-Annually Recurring Subtotal	$0			$0
Total	$0.00			$0

Social Cost

Pollutant	Social Cost ($/metric ton)	Annual Escalation Rate
Carbon Dioxide (CO_2):	$23.24	1.87%
Oxides of Nitrogen (NO_x):	$1,049.27	0.00%
Sulfur Dioxide (SO_2):	$1,635.98	0.00%

The default values should be used unless the user has reason to input alternative values.

Probabilistic Input

Parameter	Expected Value	Probability Distribution	Minimum Value	Maximum Value
Total Investment:	$149,200.00	Triangular Distribution	$126,820	$223,800
Annual Electricity Usage Savings:	141	Triangular Distribution	120	162
Annual Natural Gas Usage Savings:	-	Constant Value		
Annual Distillate Fuel Oil (#1,#2) Usage Savings:	-	Constant Value		
Social Cost of CO2 ($/metric ton):	$23.24	Triangular Distribution	$6.52	$32.36

Additional Measures		
Minimum Acceptable SIR:	2.52	The tool will calculate the probability of the SIR exceeding this value.
Minimum Attractive Rate of Return (MARR):	7.87%	The tool will calculate the probability of the AIRR exceeding this value.

Summary of Deterministic Results		
Parameter	Including Environmental Benefits	Excluding Environmental Benefits
First Year Savings	$27,742	$26,651
Simple Payback Period (in years)	5.38	5.60
Total Discounted Operational Savings	$392,674	$376,205
Savings to Investment Ratio (SIR)	2.63	2.52
Btu to Investment Ratio (BIR)	0.00094	0.00094
SIR x BIR	0.00248	0.00238
CO2 to Investment Ratio (CIR)	0.00024	0.00024
SIR x CIR	0.00062	0.00059
Adjusted Internal Rate of Return (AIRR)	8.11%	7.87%

Notes beside the table: Simple Payback Period — (total investment/first-year savings); Savings to Investment Ratio — (total discounted operational savings/total investment); AIRR — (1+d)*SIR^(1/n)-1; d=discount rate, n=years in study period

Summary of Probabilistic Results		
Parameter	Including Environmental Benefits	Excluding Environmental Benefits
Average First Year Savings	$27,648	$26,659
Average Simple Payback Period (in years)	6.04	6.26
Average Total Discounted Operational Savings	$391,240	$376,310
Average Savings to Investment Ratio (SIR)	2.38	2.29
Minimum SIR	1.78	1.72
Maximum SIR	3.08	2.96
Probability of SIR Exceeding 2.52	33.4%	22.0%
Average Btu to Investment Ratio (BIR)	0.00086	0.00086
Average SIR x Average BIR	0.00204	0.00196
Average CO2 to Investment Ratio (CIR)	0.00021	0.00021
Average SIR x Average CIR	0.00050	0.00048
Average Adjusted Internal Rate of Return (AIRR)	7.56%	7.35%
Minimum AIRR	6.02%	5.83%
Maximum AIRR	8.95%	8.74%
Probability of AIRR Exceeding 7.87%	33.4%	22.2%

Notes beside the table: Average Simple Payback Period — (total investment/first-year savings); Average SIR — (total discounted operational savings/total investment); Average AIRR — (1+d)*SIR^(1/n)-1; d=discount rate, n=years in study period

Complete Results Worksheet

Return to Instruction Worksheet

Probabilistic ECIP Report

Location:	New Mexico	**Discount Rate:**	3.0%
Project Title:	Kirtland Irrigation	**Analyst:**	ACD
Base Date:	November 1, 2010	**Preparation Date:**	February 10, 2012
BOD:	November 1, 2011		
File Name:		**Economic Life:**	20 years 0 months

1. Investment

Construction Cost:	$129,000
SIOH:	$7,600
Design Cost:	$12,600
Total Cost:	$149,200
Salvage Value of Existing Equipment:	$0
Public Utility Company:	$0
Total Investment:	$149,200

2. Energy and Water Savings (+) or Cost (-)
Base Date Savings, unit costs, & discounted savings

Item	Unit Cost	Usage Savings	Annual Savings	Discount Factor	Discounted Savings
Electricity	$24.91105	140.8 MBtu	$3,507	14.127	$49,550
Energy Subtotal		140.8 MBtu	$3,507		$49,550
Water	$1,052.00000	22 Mgal	$23,144	$14.11	$326,654
Water Subtotal		22 Mgal	$23,144.00		$326,654
Total			$26,651		$376,205

3. Non-Energy Savings (+) or Cost (-)

Item	Savings/Cost	Occurrence	Discount Factor	Discounted Savings
Annually Recurring				
Annually Recurring Subtotal	$0			$0
Non-Annually Recurring				
Non-Annually Recurring Subtotal	$0			$0
Total	$0.00			$0

4. Social Cost Information

Social Cost of CO_2 ($/metric ton)	$23.24
Social Cost of NO_x ($/metric ton)	$1,049.27
Social Cost of SO_2 ($/metric ton)	$1,635.98

5. Probabilistic Input

Parameter	Expected Value	Probability Distribution	Minimum Value	Maximum Value
Total Investment:	$149,200.00	Triangular Distribution	$126,820	$223,800
Annual Electricity Usage Savings:	$140.80	Triangular Distribution	120	162
Annual Natural Gas Usage Savings:		Constant Value		
Annual Distillate Fuel Oil (#1,#2) Usage Savings:		Constant Value		
Social Cost of CO2 ($/metric ton):	$23.24	Triangular Distribution	7	32

6. Summary of Deterministic Results

Parameter	Including Environmental Benefits	Excluding Environmental Benefits	
First Year Savings	$27,742	$26,651	
Simple Payback Period (in years)	5.38	5.60	(total investment/first-year savings)
Total Discounted Operational Savings	$392,674	$376,205	
Savings to Investment Ratio (SIR)	2.63	2.52	(total discounted operational savings/total investment)
Btu to Investment Ratio (BIR)	0.00094	0.00094	
SIR x BIR	0.00248	0.00238	
Adjusted Internal Rate of Return (AIRR)	8.11%	7.87%	(1+d)*SIR^(1/n)-1; d=discount rate, n=years in study period

7. Summary of Probabilistic Results

Parameter	Including Environmental Benefits	Excluding Environmental Benefits	
First Year Savings	$27,648	$26,659	
Simple Payback Period (in years)	6.04	6.26	(total investment/first-year savings)
Total Discounted Operational Savings	$391,240	$376,310	
Savings to Investment Ratio (SIR)	2.38	2.29	(total discounted operational savings/total investment)
Minimum SIR	1.78	1.72	
Maximum SIR	3.08	2.96	
Probability of SIR Exceeding 2.52	33%	22%	
Btu to Investment Ratio (BIR)	0.00086	0.00086	
Average SIR x BIR	0.00204	0.00196	
Adjusted Internal Rate of Return (AIRR)	7.56%	7.35%	(1+d)*SIR^(1/n)-1; d=discount rate, n=years in study period
Minimum AIRR	6.02%	5.83%	
Maximum AIRR	8.95%	8.74%	
Probability of AIRR Exceeding 7.87%	33%	22%	

Appendix B. Probabilistic Life-Cycle Full-Cost Analysis Tool User Guide

Overview

The probabilistic life-cycle full-cost analysis tool is a Microsoft Excel-based economic analysis tool for evaluating the life-cycle costs and benefits of Energy Conservation Investment Program (ECIP) projects. The tool is designed to be used in conjunction with the National Institute of Standards and Technology (NIST) Building Life-Cycle Cost (BLCC) program. The tool accepts as inputs the results found in the ECIP report provided by the ECIP module of the BLCC program. This tool complies with the methods used in the BLCC program and standards set forth in the National Institute of Standards and Technology (NIST) Handbook 135, *Life-Cycle Costing Manual for the Federal Energy Management Program.*

The probabilistic life-cycle full-cost analysis tool uses the results from the BLCC program and a Monte Carlo simulation to generate a probability distribution of the supplemental financial measures of Savings-to-Investment Ratio (SIR) and Adjusted Internal Rate of Return (AIRR). Additionally, the tool calculates both a deterministic and a mean probabilistic value of the Btu-to-Investment Ratio (BIR) and the CO_2-to-Investment Ratio (CIR). The probability distribution of the SIR provides the user with a better understanding of the uncertainty inherent in their input estimates.

The tool makes use of the EPA Emissions and Generation Resource Integrated Database (eGRID) to calculate the pollutant emissions associated with primary electricity production. The pollutant emissions associated with the burning of natural gas, distillate fuel oil (#1, #2), and liquefied petroleum gas are calculated using emissions factors from the NIST BLCC program. The pollutants considered in this tool are oxides of nitrogen (NO_x), Sulfur Dioxide (SO_2), and Carbon Dioxide (CO_2). The tool utilizes these emissions to calculate the social benefits of reduced air pollutant emissions associated with energy use reductions.

Conducting an Analysis

The format of the input worksheet of the tool is set up similarly to the format of the ECIP report from the BLCC program. This allows the user to enter values directly from the ECIP report into the probabilistic life-cycle full-cost analysis tool. Note that red fields take inputs from the ECIP report while blue fields are user-defined values.

This tool makes use of mid-period discounting convention for calculating life-cycle costs and benefits. It also utilizes constant dollar (constant purchasing power) analysis, so all costs should be entered in project base year dollars and the real discount rate (excluding

inflation) should be used. See NIST Handbook 135, Section 3.3 for additional information about inflation. NIST Handbook 135 is available at the following link:

http://www1.eere.energy.gov/femp/information/download_blcc.html

It is recommended to start with a new workbook for each new project analysis as values could have been changed by a previous user that will affect the analysis or the proper display of results.

Probabilistic Energy Conservation Investment Program Project Analysis

1. Upon opening the probabilistic life-cycle full-cost analysis tool workbook, you will first see the *Instructions* worksheet. This worksheet provides basic instructions about how to accomplish a project analysis using this tool. After reading the instructions, click on the link in step one to navigate to the *Input* worksheet.

2. The link will take you to the *Input* worksheet. This worksheet has red fields where the relevant project data is entered from the ECIP report provided by the BLCC program. All values should be entered just as they appear in the ECIP report, including any negative values. The project location should be selected from the drop-down menu in that field. The preparation date is defaulted to display the current date, but can be changed by the user. Any fields that do not have values associated with them in the ECIP report should be left blank. An explanation of each parameter can be found in the Project Data Inputs section of this guide.

3. The blue fields in the *Input* worksheet allow additional analysis beyond what is provided by the BLCC program. The Social Cost input box contains six input fields for the social costs and annual escalation rates of each of three air pollutants. Default values are provided by the tool and should be left unless the user has reason to change these values. Further explanation of these values can be found in the following section.

4. The Probabilistic Input box contains blue fields where a probability distribution for each variable can be selected. This allows the user to define the input probability distribution for each parameter in order to perform a Monte Carlo simulation. The expected value of each parameter previously entered from the ECIP report is displayed in the second column. The default probability distribution for each parameter is a constant value. If the user wishes to model the input parameters, they may select another probability distribution from the drop-down next to each parameter. The tool provides default values to define the triangular distribution or normal distribution; however, the user may change these

default values. Once a distribution is selected, the required parameters for that distribution will appear with red fields in which the values should be entered. These values will define the probability distribution. The user must input values for all parameters required for that particular distribution. See the *Explanation of Probabilistic Inputs* section of this guide for more information about the Monte Carlo simulation.

5. The additional measures box allows the user to enter the minimum attractive values of the SIR and the AIRR. The tool will then provide the probability of exceeding these values with social benefits of air pollutant emissions reductions included and excluded.

6. A summary of both deterministic and probabilistic results can be found at the bottom of the worksheet, both including and excluding the social benefits of air pollutant emissions reductions. For more complete results in the format of the ECIP report, click the *Complete Results Worksheet* link. To return to the Instructions, click the *Return to Instruction Worksheet* link. Full details of the *Results* worksheet can be found in the Results section of this guide.

Explanation of Social Cost Inputs

1. *Social Cost of CO_2:* The social cost of carbon dioxide emissions in dollars per metric ton. The Interagency Working Group on Social Cost of Carbon defined the Social Cost of CO_2 as "an estimate of the monetized damages associated with an incremental increase in carbon emissions in a given year. It is intended to include (but is not limited to) changes in net agricultural productivity, human health, property damages from increased flood risk, and the value of ecosystem services due to climate change." The value used in this research is derived from a 2010 report by the Interagency Working Group on Social Cost of Carbon. The social cost of CO_2 is used to calculate the social benefits of reduced CO_2 emissions associated with energy use reductions of ECIP projects.

2. *Social Cost of NO_x:* The social cost of nitrogen oxide emissions in dollars per metric ton. This value represents the externality costs associated with the emissions of oxides of nitrogen associated with energy production. The value used in this research is the lower range value from Roth and Ambs (2004) and is derived from control costs. The social cost of NO_x is used in this tool to calculate the social benefits of reduced NO_x emissions associated with energy use reductions of ECIP projects.

3. *Social Cost of SO_2*: The social cost of sulfur dioxide emissions in dollars per metric ton. This value represents the externality costs associated with the emissions of sulfur dioxide associated with energy production. The value used in this research is the lower range value from Roth and Ambs (2004) and is derived from control costs. The social cost of SO_2 is used in this tool to calculate the social benefits of reduced SO_2 emissions associated with energy use reductions of ECIP projects.

4. *Annual Escalation Rate:* The annual rate of increase of the social costs. The social cost of CO_2 increases at a rate of 1.87% per year. The social costs of NO_x and SO_2 are assumed to increase at the rate of inflation and therefore have an annual escalation rate of 0.

Explanation of Probabilistic Inputs

The use of Monte Carlo simulation allows the user to account for and investigate the influence of the uncertainty of input parameters on the calculated financial measures of SIR and AIRR. The user selects a probability distribution for the total initial investment, annual energy usage savings (divided by type), and the social cost of CO_2. A simulation of 1000 iterations generates a probability distribution of the financial measures. The *Probability Distribution* fields allow the user to select an assumed distribution for uncertain input parameters from a drop-down menu. The options for the probability distribution of each parameter are constant value, normal distribution, and triangular distribution.

1. Constant: Allows the user to use only the expected value for the parameter. The value of the parameter is assumed to be certain.

2. Normal Distribution: The normal distribution is represented by a bell-shaped curve with the apex of the curve appearing at expected value of the distribution. The standard deviation is a measure of the variance of the distribution about the mean. The default value of the standard deviation is provided and is based on a percentage deviation of the expected value of the parameter.

3. Triangular Distribution: The triangular distribution is represented by a triangle with the apex occurring at the expected value and the triangle terminating at the minimum and maximum values of the distribution. The default values of the minimum and maximum are provided and are based on a percentage deviation of the expected value of the parameter.

Results

The results worksheet displays the life-cycle costs and benefits of the project, along with supplemental financial measures. Results are displayed based on deterministic and probabilistic inputs, both including and excluding social benefits of reduced air pollutant emissions. These results are provided in the form of supplemental financial measures, including Savings-to-Investment Ratio (SIR), Adjusted Internal Rate of Return (AIRR), Btu-to-Investment Ratio (BIR), and CO_2-to-Investment Ratio (CIR). Sensitivity analyses of the deterministic SIR and AIRR are also provided. Finally, a histogram and cumulative probability distribution are provided for the Monte Carlo simulation of the SIR and AIRR, both including and excluding social benefits.

1. The SIR is calculated as the ratio of the total present value of operational savings to the total initial investment. The BIR is calculated as the ratio of the annual energy savings, in millions of Btu, to the total initial investment. The CIR is calculated as the ratio of the annual CO_2 emissions reductions due to energy usage reductions to the total initial investment.

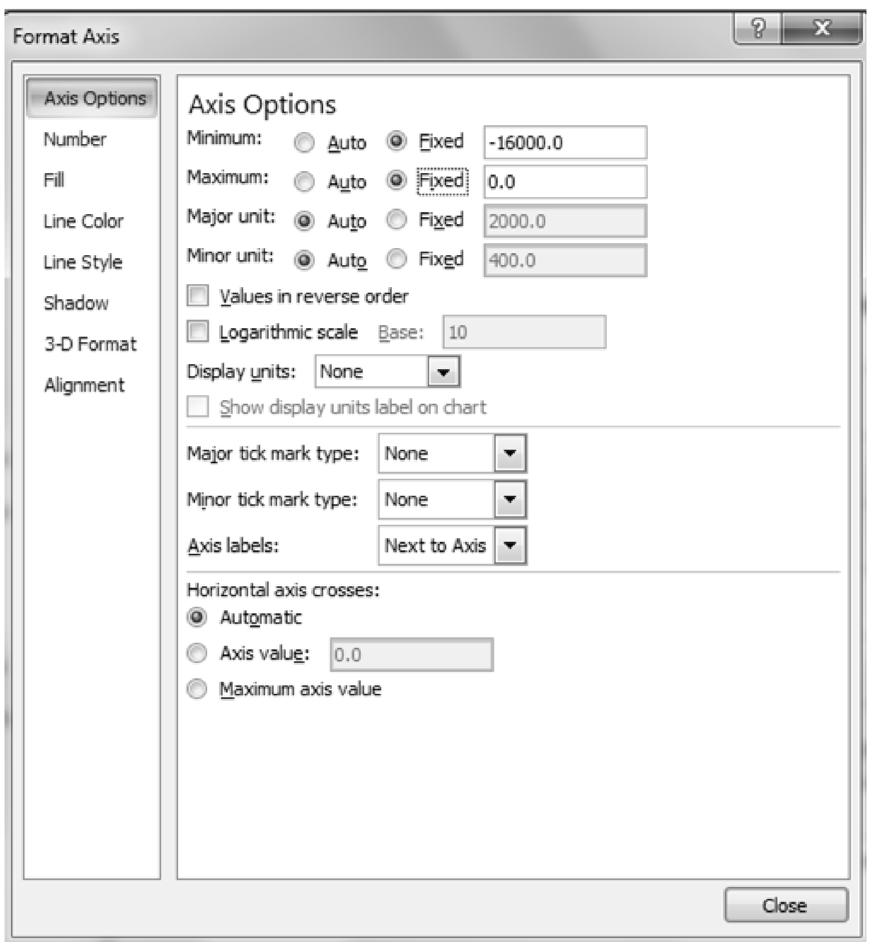
2. The probabilistic results include the minimum, maximum, and mean probabilistic values of the SIR and AIRR and the mean probabilistic values of the BIR and CIR. The tool also calculates the product of the SIR and BIR as well as the product of the SIR and CIR.

3. The Cumulative Probability graphs display both the probability distribution of the SIR and AIRR as a histogram and the cumulative probability distribution for the SIR and AIRR as a curve, both with social benefits included and excluded. The range of values of SIR is divided into 25 “bins” for use in displaying the frequency in each “bin”. These values are then used to calculate a cumulative probability distribution function, which can assist the user in determining the probability of the SIR or AIRR exceeding a specific value. The user can select a value for the SIR or AIRR, read up to the corresponding point on the curve, then over to the corresponding probability. This probability represents the probability that the actual SIR or AIRR will exceed this value.

4. The Sensitivity Analysis graphs demonstrate the change in SIR with a given percentage change in any individual parameter. Each line represents a single parameter that is varied by -20% to +20% of its expected value. At each point along the line, the SIR corresponding to that percent deviation of the parameter can be determined. The parameter corresponding to each line can be determined by the legend on the right side of the graph. The sensitivity analysis is useful for the decision-maker to determine the effect on the SIR or AIRR of a variation in

the value of a single parameter. This will help the decision-maker determine how sensitive the SIR of a project is to an uncertain parameter that may vary from the estimate provided.

a. The range of the vertical axis can be changed to better display the sensitivity analysis by right-clicking the vertical axis and selecting "Format Axis…". The window shown below will appear. Select the "Fixed" radio buttons to the right of "Minimum:" and "Maximum:". Enter the minimum and maximum values to be displayed on the vertical axis of the chart. Select the "Close" button in the bottom of the window. NOTE: These minimum and maximum values will need to be changed if any parameter values are changed as the range entered may not contain the calculated annual worth value. If after calculating a new annual worth value there is no data visible in the chart, return to the Format Axis window and select the "Auto" radio buttons to the right of "Minimum:" and "Maximum:"



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Appendix C. EPA eGRID Electricity Emissions Factors

State	State annual NOx total output emission rate (lb/MWh)	State annual SO2 total output emission rate (lb/MWh)	State annual CO2 total output emission rate (lb/MWh)	Grid Loss Factors
Alaska	3.6981	1.1704	1,134.72	1.244%
Alabama	1.7667	6.3108	1,323.47	6.471%
Arkansas	1.4851	2.8652	1,200.01	6.471%
Arizona	1.5098	1.0199	1,178.86	4.837%
California	0.3873	0.4090	565.88	4.837%
Colorado	2.5790	2.5338	1,807.07	4.837%
Connecticut	0.8218	2.3410	690.86	6.471%
Washington, D.C	4.2449	9.9445	2,781.75	6.471%
Delaware	2.6339	7.9888	1,803.71	6.471%
Flordia	2.0175	3.5676	1,257.34	6.471%
Georgia	1.5552	9.0558	1,402.69	6.471%
Hawaii	4.7462	7.8666	1,543.90	3.204%
Iowa	2.2977	5.7467	1,781.10	6.471%
Idaho	0.1377	0.2512	139.65	4.837%
Illinois	1.2252	2.9050	1,106.61	6.471%
Indiana	3.0888	11.0566	2,051.43	6.471%
Kansas	2.8138	4.6203	1,720.91	6.471%
Kentucky	3.6081	7.8239	2,095.38	6.471%
Louisiana	1.3542	1.9368	1,082.60	6.471%
Massachusetts	1.0154	3.7516	1,199.05	6.471%
Maryland	2.3051	12.0455	1,337.64	6.471%
Maine	1.1350	1.8629	527.94	6.471%
Michigan	2.0381	6.1754	1,416.79	6.471%
Minnesota	3.0408	3.5579	1,521.94	6.471%
Missouri	2.3932	5.9395	1,782.85	6.471%
Mississippi	1.9831	2.8842	1,234.42	6.471%
Montana	3.0807	3.0702	1,614.20	4.837%
North Carolina	1.0579	6.0546	1,234.97	6.471%
North Dakota	4.5203	8.7492	2,230.52	6.471%
Nebraska	2.5231	4.1959	1,427.91	6.471%
New Hampshire	0.6439	3.9637	662.99	6.471%
New Jersey	0.7303	2.6645	700.08	6.471%
New Mexico	3.9954	1.4828	1,789.28	4.837%
Nevada	1.4184	0.5321	1,162.05	4.837%
New York	0.7799	2.0658	751.51	6.471%

State	State annual NOx total output emission rate (lb/MWh)	State annual SO2 total output emission rate (lb/MWh)	State annual CO2 total output emission rate (lb/MWh)	Grid Loss Factors
Ohio	3.1346	12.5443	1,807.58	6.471%
Oklahoma	2.4056	3.7171	1,485.21	6.471%
Oregon	0.5125	0.6331	410.80	4.837%
Pennsylvania	1.8062	9.3986	1,208.02	6.471%
Rhode Island	0.2363	0.0294	908.38	6.471%
South Carolina	0.9529	3.4472	907.36	6.471%
South Dakota	3.8917	3.4380	1,226.85	6.471%
Tennessee	2.2645	5.0975	1,357.10	6.471%
Texas	0.8577	2.4889	1,307.29	6.415%
Utah	3.4373	1.3239	1,935.62	4.837%
Virginia	1.8864	5.5432	1,138.08	6.471%
Vermont	0.2289	0.0151	3.75	6.471%
Washington	0.3042	0.1247	259.19	4.837%
Wisconsin	1.8775	4.7329	1,591.72	6.471%
West Virginia	3.3444	8.7016	1,966.93	6.471%
Wyoming	3.5988	3.8151	2,835.21	4.837%
US Average	1.7939	4.7534	1,299.53	6.156%

Appendix D. Sample Feedback Questionnaire and Summary of User Feedback

Respondent: Summary of Comments

Please use this form to provide feedback on the Life-Cycle Cost Analysis tool as well as the associated User Guide. The below questions are not meant to constrain your feedback, only to provide areas to consider. Please feel free to provide any critiques or suggestions that you feel would help to improve the tool or the User Guide.

1. **Please provide any suggestions on how to improve the format or layout of the tool (instructions page, data entry, or results pages).**

- *Data entry page is easy to use*
- *Standard unit of energy measurement is MBTU (million BTU) not kWh. This makes it easier to incorporate electricity, gases, fuel oil, steam, renewable, etc.*

2. **Please provide any suggestions on how to improve the functionality of the tool.**

- *Recommend providing default values in the fields: "Discount rate," "Social cost of NOx," "Social Cost of SO2," and "Social cost of carbon." A typically Energy Manager would not be able to determine the social costs of emissions*
- *Consider "Annual Energy Savings (kwh)" vs "Annual Energy Consumption of Alternative." Many times the baseline information is not available for a project because many of our facilities are not metered. If a baseline is required, we would just have to use out best engineering guess to determine what it should be. So typically, we simply calculate the projected savings of a project and run the LCCA without comparing to a baseline.*
- *Economic analyses typically use Return on Investment (ROI), Savings-to-Investment Ratio (SIR), Simple Payback (SPB) or Internal Rate of Return (IRR) as a measure of project viability. What information does "Total Annual Worth" relay to the user in terms of the economic viability of a project.*

3. **Please provide any suggestions on features or functions that the tool currently does not have that are necessary or would be helpful.**

- *Would like to have option to include other energy sources - natural gas, steam, etc – not just electricity*

4. **Please discuss any terms found in the tool or the User Guide that were unclear or were inadequately explained.**

- *There is no guidance to distinguish between when the user should use a deterministic versus a probabilistic analysis.*

5. **Please comment on the usefulness and functionality of the probabilistic aspect of the tool.**

- *Typically, an Energy Manager would not have this detailed information. Honestly, most tactical level Energy Managers would not have a background in statistics so would not understand probability distributions*

6. **Please comment on any parts of the tool or the User Guide that you found confusing.**

- *Tool is not user friendly*
- *How are "Social Costs" determined*

7. **Please provide suggestions on how to improve the User Guide.**

- *Needs to be much more comprehensive*

8. **Please provide your overall impression of the tool.**

- *Cumbersome*
- *Lots of inputs for a minimal return on results*
- *Lots of inputs and drop-down menus with no real guidance on what values should be*

9. **Please provide any other comments not captured elsewhere.**

- *The effort is short on substance because it is totally dependent on the user to enter a substantial amount of subjective data (e.g., social costs associated with air pollutants; life expectancy values; capital, O&M, energy and disposal costs; etc.). Additionally, the input data is labor intensive and ambiguous to be an effective tool.*
- *The whole crux of the model is the LCC of energy efficiency projects as a function of greenhouse gases. The model relies on the value of inputs for Social Cost of Carbon, Social Cost of NOx, Social Cost of SO2, and Expected Life of Alternative. This concept of project energy efficiency for this model is directly borrowed from the National Institute of Standards and Technology's (NIST) BLCC computer program, which supports LCCA for energy and water conservation in federal buildings, which has the capability of estimating annual*

and lifecycle CO_2, SO_2, and NOx emissions coincident with the energy use of the building or building system being evaluated. While a simplified version of the NIST's software may be beneficial to the USAF, this model isn't there yet. Without further pinning down these central input values to remove as subjectivity and create standardization across the AF the model is of little value.

- *Attempting to assess the incremental economic impacts of air emissions is challenging and limited in value. The National Academies of Science (NRC 2009) reported that any assessment would suffer from uncertainty, speculation, and lack of information about the future and past effects emissions of greenhouse gases on the climate system, impact of climate change on the environment, and the translation of environmental impacts into economic damages.*
- *Recommend adopting the values provided in the Interagency Working Group on Social Cost of Carbon values (Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866, Interagency Working Group on Social Cost of Carbon, 2010). This reference provides CO_2 social cost based 2007 dollars and on discount rates through 2050.*
- *Truthfully I could not make out heads or tails of this tool. I would not think it is something our EM in the field would use as it was too difficult to figure out. We currently use DOE's BLCC and it is quite fine for validating all our data and projects. Also been very busy which also led to lack of time to try and figure what this guy was trying to accomplish.*
- *What is the goal or purpose of the tool? In very simple terms, what is the "Value" of using this tool?*
- *When should it be used? What results will it yield? How is it different from existing tools?*

Appendix E. Summary of Project Data

Project Number	Programmed Amnt (AFCESA)	Total Investment (ECIP Report)	Annual Energy Savings (MBtu)	Annual Dollar Amount Saved	SIR (AFCESA)	SIR (ECIP Report)	SPB (AFCESA)	SPB (ECIP Report)	BIR (AFCESA)	SIR*BIR (AFCESA)	Energy Types Saved			
											Elec	NG	DFO	LPG
ASHE121005	$330,400	$118,000	103	$9,465	1.30	1.29	13.0	14.76	0.0010619	0.0013805	X			
CZQZ118002	$687,291	$526,247	16371	$161,005	4.50	4.51	3.0	3.35	0.0237951	0.1070778	X	X		X
FSPM102214	$3,500,000	$3,500,000	6930	$78,774	1.80	1.79	8.0	7.81	0.0003814	0.0006866	X	X		
FSPM091286	$124,000	$121,118	45	$14,811	1.80	1.78	8.0	8.18	0.0003629	0.0006532	X			
GHLN117005	$266,800	$266,800	11209	$63,107	2.40	5.91	4.0	4.23	0.0419813	0.1007551		X		
HEKP124000	$113,100	$113,000	199	$9,340	1.00	1.02	11.0	11.07	0.0017456	0.0017456	X			
MHMV110059	$742,562	$661,800	38925	$581,206	12.70	12.70	1.0	1.14	0.0587991	0.7467485	X	X		
MHMV100072	$130,000	$149,200	141	$26,651	2.50	2.52	6.0	5.60	0.0001467	0.0003667	X			
MUHJ114017	$641,000	$640,961	36887	$427,741	8.20	8.21	2.0	1.51	0.0575460	0.4718774	X	X		
NZAS110301	$128,000	$128,000	2926	$70,327	6.20	6.16	2.0	1.82	0.0228594	0.1417281	X			
QSEU122014	$114,000	$125,400	11135	$81,332	4.90	4.86	2.0	1.50	0.0976754	0.4786096	X	X		
QSEU122012	$1,640,000	$1,804,000	69786	$446,946	3.90	3.85	4.0	4.00	0.0425524	0.1659545	X	X		
SGBP120038	$376,000	$375,067	47724	$405,654	15.00	15.07	1.0	0.92	0.1269255	1.9038830		X		
TYFR121135	$388,700	$428,740	12282	$381,117	7.10	7.10	1.0	1.12	0.0315733	0.2241702	X	X	X	
TYFR101089	$665,000	$580,000	410	$49,857	1.10	1.30	14.0	10.62	0.0007128	0.0007841	X			
UHHZ110225	$112,000	$112,000	38760	$182,172	6.50	6.48	1.0	0.61	0.3460714	2.2494643		X		

Appendix F. Sample ECIP Report from BLCC Program

NIST BLCC 5.3-10: ECIP Report

Consistent with Federal Life Cycle Cost Methodology and Procedures, 10 CFR, Part 436, Subpart A

The LCC calculations are based on the FEMP discount rates and energy price escalation rates updated on April 1, 2010.

Location:	U.S. Average	**Discount Rate:**	3%
Project Title:	Ramstein ECO M27, M34, M35	**Analyst:**	A. Vance rmh
Base Date:	January 1, 2011	**Preparation Date:**	Sun Apr 17 18:08:34 CEST 2011
BOD:	January 1, 2012	**Economic Life:**	10 years 0 months
File Name:	C:\Users\ralph.herran\Documents\BLCC\1ryfr121135-ENERGY CONS HANGAR HEATING CONTROLS & DOOR SEALS-M27,34,35 final trim.xml		

1. Investment

Construction Cost	$372,040
SIOH	$16,700
Design Cost	$40,000
Total Cost	$428,740
Salvage Value of Existing Equipment	$0
Public Utility Company	$0
Total Investment	$428,740

2. Energy and Water Savings (+) or Cost (-)

Base Date Savings, unit costs, & discounted savings

Item	Unit Cost	Usage Savings	Annual Savings	Discount Factor	Discounted Savings
Electricity	$40.44382	2,380.9 MBtu	$96,292	7.951	$765,584
Distillate Fuel Oil (#1, #2)	$17.13150	1,537.0 MBtu	$26,332	9.742	$256,514
Natural Gas	$30.90384	8,364.5 MBtu	$258,495	7.852	$2,029,799
Energy Subtotal		12,282.4 MBtu	$381,119		$3,051,897
Water Subtotal		0.0 Mgal	$0		$0
Total			$381,119		$3,051,897

3. Non-Energy Savings (+) or Cost (-)

Item	Savings/Cost	Occurrence	Discount Factor	Discounted Savings/Cost
Total	$0			$0
Non-Annually Recurring				
Non-Annually Recurring Subtotal	$0			$0

4. First year savings	$381,119	
5. Simple Payback Period (in years)	1.12	(total investment/first-year savings)
6. Total Discounted Operational Savings	$3,051,897	
7. Savings to Investment Ratio (SIR)	7.1	(total discounted operational savings/total investment)
8. Adjusted Internal Rate of Return (AIRR)	25.34%	(1+d)*SIR^(1/n)-1; d=discount rate, n=years in study period

Appendix G. Complete Project Ranking Results

Project Number	Deterministic SIR (Exc Social Benefits)	Deterministic SIR (Inc Social Benefits)	BIR	SIR*BIR (Exc Social Benefits)	Associated Ranking	SIR*BIR (Inc Social Benefits)	Associated Ranking
UHHZ110225	6.48	9.73	0.34607	2.24254	1	3.36705	1
SGBP120038	15.07	18.37	0.12724	1.91753	2	2.33716	2
MHMV110059	12.70	17.27	0.05882	0.74698	3	1.01602	3
QSEU122014	4.86	6.72	0.08880	0.43156	5	0.59659	5
MUHJ114017	8.21	10.79	0.05755	0.47249	4	0.62119	4
TYFR121135	7.10	7.85	0.02865	0.20340	7	0.22490	7
QSEU122012	3.85	5.14	0.03868	0.14893	8	0.19870	9
NZAS110301	6.16	8.16	0.02286	0.14083	9	0.18652	10
CZQZ118002	4.51	6.69	0.03111	0.14030	10	0.20801	8
GHLN117005	5.91	7.59	0.04201	0.24830	6	0.31894	6

Project Number	Mean Prob SIR (Exc Social Benefits)	Mean Prob SIR (Inc Social Benefits)	BIR	SIR*BIR (Exc Social Benefits)	Associated Ranking	SIR*BIR (Inc Social Benefits)	Associated Ranking
UHHZ110225	5.86	8.59	0.31316	1.83491	1	2.69080	1
SGBP120038	13.63	16.40	0.11514	1.56982	2	1.88829	2
MHMV110059	11.53	15.30	0.05333	0.61484	3	0.81574	3
QSEU122014	4.40	5.96	0.08037	0.35390	5	0.47916	5
MUHJ114017	7.44	9.60	0.05213	0.38812	4	0.50044	4
TYFR121135	6.45	7.06	0.02594	0.16725	7	0.18312	7
QSEU122012	3.48	4.56	0.03501	0.12199	8	0.15970	9
NZAS110301	5.59	7.24	0.02077	0.11613	9	0.15039	10
CZQZ118002	4.09	5.89	0.02819	0.11519	10	0.16594	8
GHLN117005	5.35	6.75	0.03802	0.20342	6	0.25677	6

Project Number	95 Percentile SIR (Exc Social Benefits)	95 Percentile SIR (Inc Social Benefits)	BIR	SIR*BIR (Exc Social Benefits)	Associated Ranking	SIR*BIR (Inc Social Benefits)	Associated Ranking
UHHZ110225	7.17	10.59	0.38307	2.74567	1	4.05830	1
SGBP120038	16.68	20.04	0.14084	2.34900	2	2.82264	2
MHMV110059	13.96	18.65	0.06406	0.89406	3	1.19432	3
QSEU122014	5.33	7.25	0.09798	0.52212	5	0.71013	5
MUHJ114017	8.98	11.57	0.06298	0.56545	4	0.72868	4
TYFR121135	7.77	8.54	0.03129	0.24311	7	0.26735	7
QSEU122012	4.24	5.58	0.04277	0.18153	8	0.23877	9
NZAS110301	6.82	8.93	0.02531	0.17248	9	0.22601	10
CZQZ118002	4.91	7.22	0.03399	0.16703	10	0.24528	8
GHLN117005	6.55	8.27	0.04650	0.30439	6	0.38474	6

Project Number	Deterministic SIR (Exc Social Benefits)	Deterministic SIR (Inc Social Benefits)	CIR	SIR*CIR (Exc Social Benefits)	Associated Ranking	SIR*CIR (Inc Social Benefits)	Associated Ranking
UHHZ110225	6.48	9.73	0.01829	0.11852	1	0.17795	1
SGBP120038	15.07	18.37	0.00672	0.10134	3	0.12352	3
MHMV110059	12.70	17.27	0.00929	0.11802	2	0.16052	2
QSEU122014	4.86	6.72	0.00560	0.02721	6	0.03761	6
MUHJ114017	8.21	10.79	0.00487	0.04001	4	0.05261	4
TYFR121135	7.10	7.85	0.00231	0.01640	8	0.01813	8
QSEU122012	3.85	5.14	0.00209	0.00803	10	0.01071	10
NZAS110301	6.16	8.16	0.00514	0.03168	5	0.04196	5
CZQZ118002	4.51	6.69	0.00396	0.01787	7	0.02649	7
GHLN117005	5.91	7.59	0.00222	0.01312	9	0.01686	9

Project Number	Mean Prob SIR (Exc Social Benefits)	Mean Prob SIR (Inc Social Benefits)	CIR	SIR*CIR (Exc Social Benefits)	Associated Ranking	SIR*CIR (Inc Social Benefits)	Associated Ranking
UHHZ110225	5.86	8.59	0.01632	0.09561	2	0.14021	1
SGBP120038	13.63	16.40	0.00600	0.08180	3	0.09840	3
MHMV110059	11.53	15.30	0.00832	0.09589	1	0.12722	2
QSEU122014	4.40	5.96	0.00500	0.02201	6	0.02980	6
MUHJ114017	7.44	9.60	0.00436	0.03244	4	0.04183	4
TYFR121135	6.45	7.06	0.00231	0.01489	7	0.01631	8
QSEU122012	3.48	4.56	0.00186	0.00649	10	0.00849	10
NZAS110301	5.59	7.24	0.00461	0.02576	5	0.03336	5
CZQZ118002	4.09	5.89	0.00354	0.01448	8	0.02086	7
GHLN117005	5.35	6.75	0.00198	0.01060	9	0.01338	9

Project Number	Deterministic SIR (Exc Social Benefits)	Associated Ranking	Deterministic SIR (Inc Social Benefits)	Associated Ranking	Mean Prob SIR (Exc Social Benefits)	Associated Ranking	Mean Prob SIR (Inc Social Benefits)	Associated Ranking
UHHZ110225	6.48	5	9.73	4	5.86	5	8.59	4
SGBP120038	15.07	1	18.37	1	13.63	1	16.40	1
MHMV110059	12.70	2	17.27	2	11.53	2	15.30	2
QSEU122014	4.86	8	6.72	8	4.40	8	5.96	8
MUHJ114017	8.21	3	10.79	3	7.44	3	9.60	3
TYFR121135	7.10	4	7.85	6	6.45	4	7.06	6
QSEU122012	3.85	10	5.14	10	3.48	10	4.56	10
NZAS110301	6.16	6	8.16	5	5.59	6	7.24	5
CZQZ118002	4.51	9	6.69	9	4.09	9	5.89	9
GHLN117005	5.91	7	7.59	7	5.35	7	6.75	7

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Vita

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14. ABSTRACT Executive Order 13514 requires federal agencies to consider economic and social benefits and costs when evaluating projects and activities based on life-cycle return on investment. The generation of energy used by federal facilities imposes social externalities, most notably air pollution, upon society. This research utilized the social costs of carbon dioxide, oxides of nitrogen, and sulfur dioxide to develop a probabilistic life-cycle full-cost analysis tool for the analysis of energy efficiency projects. This tool was then used to investigate the effects of incorporating social externalities and uncertainty into life-cycle cost analyses of energy efficiency projects. Calculation of the social benefits of air pollutant emissions reductions was found to have a statistically significant impact on the savings-to-investment ratio (SIR) of energy efficiency projects. A sensitivity analysis indicated that the SIR was most sensitive to the total initial investment of the project and the energy usage savings, but less sensitive to small changes in the values of the social benefits of air pollutants. The ranking of projects was found to be affected by the inclusion of social benefits in calculation of the SIR.			
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